Fiji pre-service primary teachers' understanding of physical science: A cultural perspective.

by

Neil Taylor, BSc (Hons), MSc (Applied Biol), MA (Ed)

A thesis submitted in fulfilment of the requirements of the degree of Doctor of Philosophy in the Centre for Mathematics and Science Education of the Queensland University of Technology.

December, 1997.

QUEENSLAND UNIVERSITY OF TECHNOLOGY
DOCTOR OF PHILOSOPHY THESIS EXAMINATION

CANDIDATE NAME	Neil Taylor
CENTRE/RESEARCH CONCENTRATION	Mathematics and Science Education
PRINCIPAL SUPERVISOR	A/Prof Keith Lucas
ASSOCIATE SUPERVISOR(S)	Dr Jim Watters
THESIS TITLE	Fiji pre-service primary teachers' understanding of physical science: A cultural perspective

Under the requirements of PhD regulation 9.2, the above candidate was examined orally by the Faculty. The members of the panel set up for this examination recommend that the thesis be accepted by the University and forwarded to the appointed Committee for examination.

Name A/Prof. Keith Lucas
Panel Chairperson (Principal Supervisor)

Name Dr James J WATTERS
Panel Member

Name DR ROD CAMPBELL
Panel Member

Name ....
Panel Member

Under the requirements of PhD regulation 9.15, it is hereby certified that the thesis of the above-named candidate has been examined. I recommend on behalf of the Thesis Examination Committee that the thesis be accepted in fulfilment of the conditions for the award of the degree of Doctor of Philosophy.

Name Dr James J. Watters
Chair of Examiners (External Thesis Examination Committee)

Date 2.6.1998

The following publications have resulted from the research described in this thesis:

Journal articles

Taylor, N., & Coll, R. (1997). The use of analogy in the teaching of solubility to pre-service primary teachers. *Australian Science Teachers' Journal, 43*(4), 58-64.

Taylor, N., & Lucas, K. (1997). The trial of an innovative science programme for pre-service primary teachers in Fiji. *Asia-Pacific Journal of Teacher Education, 25*(3), 325-343.

Taylor, N., & Macpherson, C. R. (1997). Traditional and religious beliefs and the teaching of science in Fiji. *New Zealand Journal of Educational Studies, 32*(2), 191-205.

Taylor, N. (1997). Some reflections on the challenges facing science educators in Fiji. *Journal of Practice in Education for Development, 3*(2), 67-69.

Conference presentation

Taylor, N., Lucas, K., & Watters, J. (1998, April). *Challenging pre-service elementary teachers' assumptions about the teaching of science in Fiji.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Abstract

Science and technology are promoted as major contributors to national development. Consequently, improved science education has been placed high on the agenda of tasks to be tackled in many developing countries, although progress has often been limited. In fact there have been claims that the enormous investment in teaching science in developing countries has basically failed, with many reports of how efforts to teach science in developing countries often result in rote learning of strange concepts, mere copying of factual information, and a general lack of understanding on the part of local students. These generalisations can be applied to science education in Fiji. Muralidhar (1989) has described a situation in which upper primary and middle school students in Fiji were given little opportunity to engage in practical work; an extremely didactic form of teacher exposition was the predominant method of instruction during science lessons. He concluded that amongst other things, teachers' limited understanding, particularly of aspects of physical science, resulted in their rigid adherence to the text book or the omission of certain activities or topics.

Although many of the problems associated with science education in developing countries have been documented, few attempts have been made to understand how non-Western students might better learn science. This study addresses the issue of Fiji pre-service primary teachers' understanding of a key aspect of physical science, namely, matter and how it changes, and their responses to learning experiences based on a constructivist epistemology.

Initial interviews were used to probe pre-service primary teachers' understanding of this domain of science. The data were analysed to identify students' alternative and scientific conceptions. These conceptions were then used to construct Concept Profile Inventories (CPI) which allowed for qualitative comparison of the concepts of the two ethnic groups who took part in the study. This phase of the study also provided some insight into the interaction of scientific information and traditional beliefs in non-Western societies.

A quantitative comparison of the groups' conceptions was conducted using a Science Concept Survey instrument developed from the CPIs. These data provided considerable insight into the aspects of matter where the pre-service teachers' understanding was particularly weak.

On the basis of these preliminary findings, a six-week teaching program aimed at improving the students' understanding of matter was implemented in an experimental design with a group of students. The intervention involved elements of pedagogy such as the use of analogies and concept maps which were novel to most of those who took part. At the conclusion of the teaching programme, the learning outcomes of the experimental group were compared with those of a control group taught in a more traditional manner. These outcomes were assessed quantitatively by means of pre- and post-tests and a delayed post-test, and qualitatively using an interview protocol. The students' views on the various teaching strategies used with the experimental group were also sought.

The findings indicate that in the domain of matter little variation exists in the alternative conceptions held by Fijian and Indian students suggesting that cultural influences may be minimal in their construction. Furthermore, the teaching strategies implemented with the experimental group of students, although largely derived from Western research, showed considerable promise in the context of Fiji, where they appeared to be effective in improving the understanding of students from different cultural backgrounds. These outcomes may be of significance to those involved in teacher education and curriculum development in other developing countries.

Descriptors:

Fiji; Indian; Fijian; Matter; Scientific Conceptions; Alternative Conceptions; Understanding; Science Education; Traditional Beliefs; Pre-Service Primary Teachers.

Acknowledgements

The author wishes to express his appreciation for the assistance obtained from his supervisors at Queensland University of Technology. Thanks must go to Associate Professor Keith Lucas and Dr. Jim Watters for their valuable input and guidance throughout the project. A number of other members of the Centre for Mathematics and Science Education must also be thanked for their assistance in critically reviewing the thesis. The efforts of Martin Lambert for his advice on statistical matters and those of Tracy Ellis for producing various diagrams for this thesis are also very much appreciated.

My thanks go to the Fiji Ministry of Education for allowing me to undertake my research in Fiji, and also to the staff and students of the Lautoka Teachers' College for all of their assistance.

Finally, the author wishes to thank his wife, Subhashni Nathan, for her support and forbearance throughout the three years of this project.

Contents

3 Methodology

4 Pilot Study

5 The Teaching Intervention

6 Results and Data Analysis of Elicitation and Prevalence Phases

List of Tables and Figures

Tables

Figures

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously submitted or written by another person except where due reference is made. I undertake to retain the original collected data on which the thesis is based for a minimum of five years, in accordance with University Ethics Guidelines.

Signed: ____________________________________ Date: _________________

Chapter 1

Introduction

1.1 Background and justification

This study addresses a number of concerns and issues relating to Fiji pre-service primary school teachers' understanding of physical science. In selecting this area of research I have been influenced by two main factors. The first of these was an in-depth study conducted by Muralidhar (1989), in which he documented his observations of how the Fiji Basic Science course was being implemented by classroom teachers. The second was my own experience of running in-service science courses for primary level teachers while working at the University of the South Pacific (USP) from 1990 to 1994.

Muralidhar's study represents the most significant piece of research into science education in Fiji to date. He describes a rather depressing situation in which students were given little opportunity to carry out practical activities in science and an extremely didactic form of teacher exposition was the predominant form of instruction during science lessons. This is exemplified by the following observations he recorded as part of his research. The first refers to the displacement of copper from copper sulfate solution using steel wool:

> Students were not given the opportunity even to handle this simple activity; the teacher did the demonstration and provided the running commentary...Right at the start of the lesson the teacher revealed the hidden identity of blue stone; steel wool was supposed to do that. Once again students were forced to accept the colour change under threat. (p. 249)

A second example refers to observations of a later lesson on carbon dioxide with a different teacher:

> Once again, the students just sat and copied the questions and diagrams - even before 'seeing' the activity, they were asked to record their answers...The activity was only incidental to the lesson; the students knew the result already. (p. 250)

These are only two of many such observations Muralidhar made with upper primary and middle school science classes. In his conclusions about the teaching he had observed, Muralidhar suggested that amongst other things, teachers' limited conceptual understanding of the material they were teaching affected both their confidence and their style of teaching. However, probing this assertion further was beyond the scope of his study.

My own experiences working with primary teachers are consistent with Muralidhar's findings. While conducting in-service science courses with practising primary school teachers, some of whom had considerable experience, it became clear that many of these teachers had only a partial understanding of the concepts underpinning the material they were using. A number of these teachers also expressed alternative conceptions when attempting to explain the outcomes of various activities related to such topics as air pressure and heat. From further discussions and observations it emerged that some teachers relied almost exclusively on the course materials to help them through their teaching of science, often quoting from them verbatim. Others simply omitted activities which they found difficult to understand and thus explain to their students. It appeared that the level of primary teachers' science content knowledge may be an important factor in determining the quality of science education in the classroom.

Primary teachers are a crucial link in the chain of science teaching because they are laying the foundation for the learning of science in later years. Thus it is vital that they have a sound understanding of the science concepts which they teach. Without this teachers are unlikely to provide the types of learning experiences their students require if they themselves are to achieve the learning of science with understanding.

The problems facing science education in Fiji are further compounded by the disparity in performance of the two major ethnic groups which dominate the country's population, namely the indigenous Fijians and the ethnic Indians. Indigenous Fijians lag behind the Indians in academic achievement generally, but this is especially marked in mathematics and science (Macpherson & Taylor, 1994; Stewart, 1983) and manifests itself in an acute lack of Fijians teaching science and mathematics at the senior high school level throughout the country. According to the Ministry of Education, only about 20-25% of high school chemistry and physics teachers are Fijian (Fiji Ministry of Education, pers. com.). This underachievement of Fijian students in science and mathematics is a matter of great concern to the government, but to date no substantial research has been undertaken into the possible causes or solutions.

Nevertheless, a number of tentative suggestions have been put forward to account for this problem. One of the more plausible of these has been presented recently by Nabobo and Teasdale (1994) who argue that there is a total disregard of Fijian ways of learning in the formal school system. Certainly it is possible that the formalistic, didactic style of teaching evident in many of the science classrooms in Fiji may be at odds with the oral traditions of the Fijian culture, where discussion of ideas is the predominant mode of information sharing. Ninnes (1991) suggests that the individualised nature of much classroom communication often contrasts with group values such as humility in Pacific cultures. This view finds support from a recent study on science education conducted in New Zealand (Austin, pers. com.) which indicated that indigenous Pacific Island students had a stronger preference for group work and co-operative learning than Asian or European students. This argument has also been put forward by Taylor (1995) in attempting to explain the problems facing African students. Taylor argues that there is a discrepancy between African culture, which traditionally valued co-operativeness in its indigenous education, and the very bookish colonial education system which superseded this and still predominates today.

Clearly the problems documented above have a significant impact on the quality of science education provided in Fiji schools. They are also likely to prove extremely difficult to alleviate. One possible starting point, however, would be to conduct in-depth research into pre-service primary teachers' understanding of certain science concepts and how this understanding could be improved. That is, study the process of conceptual change in relation to cultural and social contexts. This would provide insight not only into whether the two major ethnic groups face different conceptual problems with aspects of science, but also whether a model of instruction which involved a more interactive pedagogy would help improve understanding of science in both ethnic groups while proving to be more sensitive to the cultural needs of the Fijian students.

1.2 Nature and scope of the study

The concerns expressed in the previous section provide the background and justification for undertaking a study into primary teachers' (or in this case pre-service primary teachers') understanding of physical science, which compares the needs of the two major ethnic groups. In this respect, this study in Fiji offered a unique opportunity to conduct research with students from two markedly different cultures, who despite differential performance in science, had reached a sufficient educational standard to gain entry into a tertiary level institution for which competition for places was intense. While many of these students exhibited a weak understanding of physical science, they were able to articulate both their explanations of observed phenomena and their views about the teaching and learning of science in a way in which younger students in Fiji may have found more difficult. Consequently, the study provided information which should prove useful to teacher educators in Fiji involved in science instruction.

In Fiji, primary level teachers have to cover a wide range of science topics encompassing both physical and biological science concepts. This study was limited to physical science concepts and more specifically to *Matter and how it changes* and the application of Kinetic Theory to this domain for the following reasons:

1. Evidence from the literature indicates that primary teachers have particular problems with physical science concepts and find this area of science much more threatening than the biological aspects (Kruger & Summers, 1989).

2. Matter and Kinetic Theory were chosen as the specific domain of investigation because an understanding of this theory is crucial to understanding many other aspects of science. This theory, which

states that all matter is composed of hypothetical particles which are constantly in motion, provides a basis for explaining many of the observable aspects of scientific phenomena.

3. Correspondence with those involved in pre-service training of primary teachers, together with my own experience of in-service training with practising primary teachers, indicated that this is a conceptual area which teachers have some difficulty understanding and applying to other topics.

The study focused on pre-service primary school teachers rather than practising teachers and there were a number of reasons for this:

1. Working at Lautoka Teachers' College offered relatively easy access to a large group (over 300) of prospective primary school teachers. This circumvented the problem of gaining access to a large number of individual primary schools, which would have been necessary in order to obtain a large enough sample for the purposes of this study.

2. I already had a limited knowledge of this context having previously conducted some research at the college where I worked closely with the vice principal and lecturer in science education.

3. The principal of Lautoka Teachers' College along with the lecturers in science education had given the proposed study their full support and had indicated their willingness to assist with the research where necessary.

The Permanent Secretary of the Fiji Ministry for Education, Women, Culture, Science and Technology also provided written approval for the research project to be undertaken in Fiji.

Finally, although this study was undertaken in the context of Fiji which has unique racial and cultural characteristics, the outcomes may be of value to educators in other developing countries. As will be discussed later, many of these countries share common problems in relation to science education. Despite these problems being highlighted, Baker and Taylor (1995) assert that few attempts have been made to understand how non-Western students might better learn science, a discipline which they argue has been largely imported from foreign cultures. By trialing and conducting detailed evaluation of a series of novel teaching strategies in Fiji, this study offers insights into their effectiveness as possible alternatives to the extremely didactic form of science instruction often encountered in non-Western science learning environments. It was hoped to demonstrate that these strategies could help students develop conceptual understanding rather than the rote learning of scientific facts often associated with the more formalistic approach.

1.3 Aim of the study

The principal aim of the study was to investigate Fiji pre-service primary school teachers' understanding of *Matter and how it changes* and the application of Kinetic Theory to this domain of science, and if necessary, to suggest how this understanding could be improved. This involved the following objectives:

1. To identify and compare alternative conceptions held by individuals of both ethnic groups.

2. To determine the prevalence of these alternative conceptions in the wider population of pre-service teachers.

3. To design and implement an intervention, which would be informed by a constructivist view of learning, to improve conceptual understanding.

4. To evaluate the impact of the intervention and in particular its comparative effectiveness with the two major ethnic groups within the student population of the college, namely the ethnic Indians and the indigenous Fijians.

In an effort to achieve these objectives this study employs a mixed methodology which, in the main comprises interpretive and naturalistic methods of data collection, but also includes both a major quantitative survey and a teaching intervention based on a quasi-experimental design involving pre-test-post-test non-equivalent group comparison. This mix of qualitative and quantitative methods has been sequenced in order to diagnose existing problems of understanding in physical science and to implement strategies aimed at alleviating these problems and providing the students with improved conceptual understanding.

1.4 Definitions and assumptions

It is important to define certain words and terms which will be used frequently throughout this study:

Concept - a general mental notion of things or events, used as a basis for thought and expressed through symbolic language. Concepts can be thought of as ranging from easily imagined e.g., animal, to highly abstract e.g., atom (Page & Thomas, 1979).

Conceptual understanding - when newly acquired concepts can be related to the prior existing knowledge of the learner in a substantive, non-arbitrary way (this is also referred to as meaningful learning) (adapted from Ausubel, 1968).

Rote learning - the arbitrary, verbatim and non-substantive incorporation of new concepts by the learner when no attempt is made to link newly acquired concepts to existing knowledge (adapted from Ausubel, 1968).

Scientific view - the consensual view of the world currently held by the scientific community (adapted from Summers, 1992).

Alternative conceptions - beliefs which differ from the currently accepted scientific view and from the intended outcome of learning experiences, but which are sensible and useful to individuals who hold them (Driver, 1981). These are also referred to in the literature as: misconceptions, alternative frameworks, and children's science.

Developing countries - countries which are characterised by relatively low levels of per capita income, limited industrialisation and restricted infrastructure (Vulliamy, 1990).

Western countries - countries which are highly industrialised and urbanised and which have high per capita incomes (Vulliamy, 1990).

Culture - The pattern of shared behaviour which is transmitted from one generation to another (Dasen, 1974).

The following assumptions were central to this study:

1. That individuals are purposeful and construct their own explanations for physical phenomena as a result of social interaction and contact with the physical environment.

2. That personal and social constructs which provide such explanations can often be in conflict with the accepted scientific view thus making the acquisition of an understanding of the scientific view more difficult.

3. That it is important for teachers of science to have a conceptual understanding, which is in accord with the scientific view, of the topics they teach.

4. That the cultural groups referred to in this study, although not homogeneous, have general characteristics which appear to affect their educational performance in the context of the current Fiji education system.

1.5 The organisation of this thesis

This thesis is organised into eight chapters. Chapter 2 provides an historical perspective to the study and a review of other pertinent research conducted in both Western and developing countries. The contextual background is also discussed with a description of the education system in Fiji and a discussion of previous research in science education in that country, specifically that which relates to the comparative performances of Indians and Fijians. This leads on to chapter 3 which deals with the theoretical framework for the study along with the methodological background, research design, data collection and analysis procedures.

Chapter 4 describes and reports the results of a small scale pilot study undertaken with pre-service primary teachers in Australia. This study was primarily intended to allow the researcher to become familiar with and fine-tune the research methods for the first phase of the design and identify potential problems before embarking on the main study which was undertaken in Fiji. However, as the data from the pilot study were derived from students in a Western context, they proved to be of interest later when comparing their conceptions with those of the students in Fiji.

The fifth chapter outlines the rationale behind the teaching intervention with its various teaching strategies, as this was of particular importance to the whole study, while the data analysis and results of the whole study are reported in chapters 6 and 7. Finally, these findings have been discussed in relation to other research in chapter 8, the conclusions along with certain implications for the teaching of science in Fiji.

1.6 Significance of the study

This study is the first of its kind to be undertaken in Fiji, and as stated previously, the initial phases provided information as to the types of conceptual difficulties Fiji primary teachers have with physical science, and how prevalent these are. The data obtained also indicate the extent to which there were qualitative and quantitative differences in the alternative conceptions of the two major ethnic groups in Fiji, and give some insight into the role of culture in developing alternative conceptions in physical science.

The implementation and evaluation of the teaching experiment based on a constructivist epistemology, provided evidence for the effectiveness of such an approach in the Fiji context. It was of particular significance in determining whether such a strategy is more effective in meeting the needs of the indigenous Fijians than the more traditional transmissive approach to science teaching presently employed throughout much of Fiji. Such information should be of value to those involved in pre-service and in-service science education in the primary sector.

Chapter 2

Literature Review

2.1 Introduction

In this survey of the literature I begin by briefly discussing the paradigm shifts which took place in science and cognitive psychology earlier this century and which have ultimately had a major impact on thinking in science education as they led to the rise of the constructivist movement. I then go on to review some of the more significant findings from the substantial research influenced by the growth of constructivism. In this research various techniques have been used to probe learners' understanding of science and identify their alternative conceptions (ideas differing from the scientific view). Some of the implications of this research for science instruction are also discussed. Specific attention is paid to studies on alternative conceptions related to *Matter and how it changes* and the application of Kinetic Theory to this domain, as an understanding of this theory is crucial for explaining so many other aspects of science. It is also the topic I chose to investigate with the students in Fiji.

This leads into a review of literature specific to primary teachers' understanding of science, and a discussion of the types of knowledge teachers at this level need in order to teach science effectively. The impact that a lack of understanding of the discipline can have on primary teachers' attitudes to science and its teaching is also examined. There then follows a discussion of the major strategies which have been designed to effect conceptual change in science and thus give learners a better conceptual understanding of this subject. The advantages and disadvantages of different approaches to this problem are discussed in some detail.

Finally, the particular problems of teaching science effectively in developing countries are explored. Specific reference is made to Fiji and the Lautoka Teachers' College, as it is this college, which trains primary level teachers for Fiji schools, which provides the context of my study.

2.2 Historical perspective

The twentieth century has witnessed a major shift in scientific thinking. Drastic changes in the ideas of modern physics started to question the prevailing empiricist belief that science could make 'absolutist' claims, in other words that once knowledge is acquired it can be described in absolutist terms such as 'true' or 'proven.' Karl Popper (1959) raised questions about the possibility of ever proving or confirming knowledge. This led to the proposal that knowledge was not discovered but was instead the result of construction by the human mind. Unlike empiricism, which claimed that observation came before theory, constructivism postulated that theory preceded observation, and that observations can be selected and conducted only through theoretical expectations. Therefore, our own constructed theories determine how we perceive the world (Nussbaum, 1989).

A similar paradigm shift has taken place in psychology. The decades following the 1920s had been dominated by behaviourism, a school of thought which emphasised the passivity of the mind, with information from the environment providing an input which is directly transmitted to, and accumulated by, the learner (Gilbert & Watts, 1983). This had resulted in what is called the 'cultural transmissive' approach (Pope & Gilbert, 1983) or 'conduit model' (Tobin, Briscoe, & Holman, 1990) which became dominant in Western education. The most extreme advocates of this approach contended that absolute truth could be accumulated bit by bit, subject by subject, thus implying that knowledge is piped from the full container of the teacher's head to the empty vessels of the students' heads.

Teaching based on behaviourist thinking placed little or no emphasis on the student's own conceptions or active participation and, as Yager (1991) suggested, it placed a low premium on learning with understanding:

> If the goal is to get students to replicate a certain behavior, this method works well; but if understanding, synthesis, eventual application, and the ability to use information in a new situation is our goal in education, a behaviorist approach is not successful. Because there is no place in the model for understanding, it is not surprising that behaviorist training rarely produces it. (p. 54)

However, during the 1960s and 70s new cognitive theories began to emerge which challenged the behaviourist view and regarded knowledge as being produced by transactions between a person and the environment. An emphasis was thus placed upon the active person reaching out to make sense of events by engaging in the construction and interpretation of individual experiences (Pope & Gilbert, 1983).

Such thinking was not entirely new, and educators such as Dewey (1916) had previously called for the development of an active approach to teaching and learning. However, Nussbaum (1989) contends that it was a combination of a greater awareness of the paradigm shift in the philosophy of science, along with the new theories in cognitive psychology which ultimately led to the major drive within science education for a new approach to teaching, one which would perceive students as active thinkers who construct personal meaning that could in turn help them form conceptual frameworks. According to Tobin, Kahle and Fraser (1990), this constructivist view of learning is defined as the acquisition of knowledge by individuals through a process of construction that occurs as sensory data are given meaning in terms of prior knowledge. Learning is always an interpretative process and always involves individual constructions. Thus, from a constructivist perspective, to learn science implies direct experience with science as a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meaning negotiated with peers and teachers.

This belief, that learners are purposive, constructing knowledge through social interaction, and experiences with the physical environment, was a radical shift from the behaviourist view of learning which had put the learner in a passive role as an absorber of information (Driver & Bell, 1986; Driver & Easley, 1978), or as coming to science lessons with a 'blank mind' which can be filled with the teacher's science (Gilbert, Osborne, & Fensham, 1982). It acknowledged that students bring to their school learning in science ideas, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. Further, these ideas could differ from the currently accepted scientific view, and from the intended learning outcome (Driver, 1981). The systematic attempt to recognise students' ideas, referred to by such terms as 'alternative frameworks', or 'children's science', and to build upon them for instructional strategies, led to the 'Constructivist Approach', which was the application of constructivism to education.

Thus for some time the mantra of the constructivist movement has been 'students actively construct their own knowledge' (Bereiter, 1994), and according, to Nussbaum (1989) all versions of the constructivism in teaching require that both the teacher and the curricular activities help the students actively to construct their own meaning of the materials under study.

However, this may be an oversimplification, as within the constructivist movement there are now a number of differing traditions, resulting in a range of accounts of how knowledge construction takes place (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Cobb (1994) identifies two major trends in science and mathematics education, the constructivist perspective, which is the belief that students actively construct their scientific ways of knowing as they strive to make sense of the world they experience, and the sociocultural perspective, the belief that scientific knowledge is socially constructed. This second perspective emphasises the influence of the learner's cultural context when acquiring knowledge, rather than his or her personal experiences. According to O'Loughlin (1992), critics of the constructivist perspective argue that knowledge is socially constructed, and that we cannot talk about knowing without considering the historically and socially constituted self that engages in the process of knowing.

Thus proponents of these two schools of thought view knowledge construction in different ways. As Bereiter (1994) puts it:

> Stripped to their essentials, constructivism tells us to pay close attention to the mental activities of the learner, and socioculturalism tells us to pay close attention to cultural practices in the learner's milieu. (p. 21)

However, Bereiter (1994) and Cobb (1994) agree that these proposals are not incompatible as mathematics or science learning should be viewed both as a process of individual construction and enculturation into the mathematical or scientific practices of wider society. In fact Bereiter argues that the modern constructivist program has already assimilated the sociocultural perspective, in so far as it applies to mathematics and science as disciplines.

Cobern (1993a), using somewhat different terminology, has identified three strands of constructivism. He suggests that, as the early research emphasis in constructivism was clearly on the individual, this is best termed personal constructivism. Secondly, he points to research by Solomon (1987) which focused on social interactions in the classroom and led her to the conclusion that, as students interact with one another and with teachers, they develop ideas that are commonly held and offer a common frame of reference in which communication and discourse can take place. This focus was similar to the views of Vygotsky (1962) who claimed that individual thought processes originated in conversations with others, thus knowledge was socially constructed through experiences in a social environment mediated by language. Cobern (1993a) also draws on ideas from cultural anthropology to put forward the further concept of contextual constructivism. This he argues, if taken to its logical conclusion, compels the investigation of student views within the cultural context that gives meaning to those views, as a fundamental aspect of any culture is a shared or core worldview. Thus, in terms of science education, this theory argues that the educator must first try to understand the world as students understand it.

Clearly these avenues of constructivism have much in common with the trends identified by Cobb (1994). Cobern, like Bereiter, also believes that the various avenues of constructivism outlined above are not mutually exclusive, and all three should be brought together to achieve an adequate approach to teaching and learning research.

What is clear from the section above, which outlines some of the different emphases given to constructivism, is that there is still much debate about what influences learners' acquisition of knowledge. Indeed the term 'constructivism', so widely used in science and mathematics educational research, is not always clearly defined, but is often applied in a rather 'broad spectrum' manner. In fact, according to

Cobern (1996a), for all its apparent simplicity the term constructivism is defined differently by different people.

Nevertheless, as a result of the rise of the constructivism and science educators' subsequent desire to discover students' prior conceptions and the perceived debilitating effects they could have on learning, an enormous amount of research has been generated since the mid 1970s. There are now substantial bibliographies, with over 1000 references, into investigations of children's conceptions in science (Carmichael, Driver, Holding, Philips, Twigger, & Watts, 1990; Pfundt & Duit, 1994), and four international seminars have been conducted on the topic (Helm & Novak, 1983; Novak, 1987; Novak, 1993; Abrams, in press). Gilbert and Swift (1985) have called this emerging and extending research approach the Alternative Conception Movement.

Since the early days of this research, perceptions about alternative conceptions have gradually changed. They are no longer viewed as being only debilitating for the learner, but are increasingly being viewed in a more positive light, as structures which can be built upon rather than requiring to be extinguished. This will be discussed at greater length in later sections.

2.3 Some important findings from research on alternative conceptions in science

Although it is not the intention here to review the body of research referred to above in great detail, it is worth discussing some of the general findings. The vast majority of research on alternative conceptions has been carried out with school-age children, but some of the similarities between children's conceptions in science, and those of primary level teachers are very strong, not least because many of the ideas about science which primary teachers hold will have been formed during childhood. The findings also have important implications for the process of conceptual change in scientific understanding, an issue which will be discussed in a later section.

2.3.1 The origins of alternative conceptions

There is now widespread agreement that individuals construct 'models' or 'schemes' which are used to interpret their experiences (e.g., Driver & Oldham, 1986; Kelly, 1955; Novak, 1987; Nussbaum & Sharoni-Dagan, 1983). Thus learners come to school with what appear to be well formed views on many scientific matters which are often at odds with accepted scientific thinking. Solomon (1983) distinguishes such views, which she calls the life-world domain of knowledge, from the domain of symbolic scientific knowledge and points to the problems children have in relating the two. Osborne, Bell and Gilbert (1982) have suggested a number of reasons why children generate views that are different from those of scientists:

1. Children view things from a self-centred or human-centred point of view and tend to consider only those entities that follow directly from everyday experiences.

2. Children's experiences of the world are limited and tend not to include contrived experimental situations, e.g., water boiling at low pressure, frictionless situations.

3. Children tend not to be interested in particular explanations for specific events and tend not to be concerned with the need to have mutually coherent and non-contradictory explanations for a variety of phenomena.

4. The everyday use of language tends to be subtly different from the language of science particularly with regard to basic and important words like 'animal,' 'friction' and 'force,' and these everyday meanings tend to shape children's constructions.

The last view is supported by Brook and Driver (1989) who note that notions like sucking are more likely to be supported by everyday discourse than the scientific view and it is a model that is therefore sustained and reinforced.

This has led Gilbert, Osborne and Fensham (1982) to describe five different patterns of children's science for which they provide evidence from their own research:

1. *Nonobservables do not exist* - e.g., 'If you cannot feel an electric current it is not present.'

2. *Self-centred or human-centred viewpoint* - When human concerns govern the interpretations made of phenomena, e.g., 'What is the difference ice and water?' 'You can't drink it (ice) very good.'

3. *Endowing objects with the characteristics of humans or other animals (anthropomorphism)* - Children often endow objects with a feeling, a will, or a purpose., e.g., 'Oh, it's cold in there and it's (the cold) trying to get out...'

4. *Endowing objects with a certain amount of a physical property* - Implying that heat is a physical entity, e.g., 'The heat makes the air bubbles come out of the element.'

5. *Everyday Language* - Children make sense of statements in science by using the everyday interpretation of the words.

While many alternative conceptions may be environmentally derived, resulting from interaction with the physical environment (Driver & Easley, 1978) or socially derived, based on interactions with family members, peers or the media (Solomon, 1983), Strike and Posner (1992) question if, in many instances, these alternative conceptions are clearly articulated or symbolically formulated. They suggest that, prior to instruction, many alternative conceptions do not exist in any form of representation as alternative formulations to preferred conceptions. Rather, they believe that the actual alternative conception may be generated on the spot as a consequence of instruction. The learner being given a problem to solve or some alternatives among which to choose may produce an alternative conception to solve the problem.

Yates, Bessman, Dunne, Jerston, Sly and Wendelboe (1988) have also questioned whether students come to problems with naive or indigenous theories. Their work on conceptions of motion has led them to the conclusion that students mentally enact the problem situation in order to obtain a solution rather than using a pre-formed theory of their own.

The view that instructional experiences may generate alternative conceptions is supported by a number of authors (Bar, 1990; Bar & Travis, 1991; Osborne & Cosgrove, 1983; Scott, 1992; Stavy, 1988).

Scott's (1992) case study of the development of a student's ideas relating to the structure of matter revealed that alternative conceptions were developed after the start of teaching. This led Scott to conclude:

> The term prior conception is suggestive of a situation where the student has formulated ideas about some topic in advance of any instruction. Data from this study have been used to argue that this need not necessarily be the case. That in the context of the particulate theory of matter, and indeed any domain of science, students' alternative conceptions are just as likely to develop from dynamic interactions between existing and taught ideas during instruction. (p. 223)

Although Scott provides good evidence of inconsistencies in his subject's prior conceptions of matter (continuous on one occasion and particulate on another), perhaps his conclusions should be treated with some caution as they are based on work with a single student. However, Stavy's (1988) work with a group of 80 young students (grades four to seven) supports Scott. She was able to demonstrate that prior to instruction these students, although they knew the term gas, and could provide examples of gases, had not developed a spontaneous concept of any of the properties or attributes of a gas. Only after completing a unit of instruction entitled *The Structure of Matter* did the concept of gases having properties develop.

Bar and Travis (1991) provide evidence of a different kind for the effect of instruction on students' conceptions. They compared students' responses to open-ended questions with those to multiple-choice questions and were able to demonstrate that answers very rarely found in the open-ended questions were often commonly selected in multiple-choice tests, and in some cases students would choose the wrong answer from the multiple-choice test even though they had provided the correct answer during the open-ended tests. Similar evidence has been provided by Osborne and Cosgrove (1983) who found, perhaps not unexpectedly, that students often opted for what appeared to be the most 'scientific' answer even though it was not correct. These authors used this evidence to suggest that, what they termed misconceptions, can be instructionally imposed.

Thus there appears to be evidence from a variety of sources to support the assertion of Strike and Posner (1992) that many alternative conceptions may not be clearly articulated prior to instruction.

2.3.2 The resistance of alternative conceptions to change

One of the most consistent and important findings in the alternative conceptions literature is that alternative conceptions are highly robust, and resistant to change (e.g., Clement, 1982; Driver, Guesne, & Tiberghien, 1985). Researchers have commented on the persistent nature of students' views, even in the face of contradictory science teaching (Osborne & Gilbert, 1980b; Tasker, 1980).

Recent work by Shepardson, Moje and Kennard-McClelland (1994) on the effectiveness of scientific demonstrations in teaching illustrates not only that alternative conceptions can originate as a result of instruction, but also that they are extremely resistant to change. Here the authors used the 'egg and bottle' demonstration to illustrate the effect of air pressure. However, even after observing and discussing the demonstration, one third of students explained the outcome in terms of fire or heat rather than air pressure. The concept of gravity, which was not a theme in the student guides was also mentioned by a number of subjects interviewed. They linked the concept of gravity and air pressure to explain the demonstration, illustrating what Vygotsky (1986) called 'chaining' of concepts in an attempt to derive an explanation for what was observed. This example illustrates what may appear to be superficially contradictory, namely that although alternate conceptions may be easily generated, once established they can be extremely tenacious.

A number of authors (Hewson, 1988; Strike & Posner; 1982, 1992) use the metaphor of a 'conceptual ecology' to explain why some conceptions are resistant to change. This metaphor was first proposed by Toulmin (1972), who suggested that knowledge develops as a result of the dynamic interaction between individuals and their environment. He described this interaction as a conceptual ecology, and went on to suggest that conceptual frameworks, or systems of knowledge, are adaptations to particular environments in the same way that biological organisms are biologically adapted to their environment. Strike and Posner (1982, 1992) have attempted to describe the general features of an individual's conceptual ecology, which they argue will comprise such cognitive artefacts as: anomalies; analogies and metaphors; epistemological beliefs; metaphysical beliefs and knowledge from a wide range of fields. These authors believe that this model provides good reasons to suppose that the reappraisal of one concept will require the reappraisal and modification of others. Thus some conceptions will be quite resistant to change, if they are embedded in a web of other concepts that lend plausibility or intelligibility.

> When an alternative conception is firmly embedded in a conceptual context, the cost required for its revision is high. Students will have to alter other concepts as well. Moreover, unless these concepts are altered, they will continue to maintain the misconceptions. Also, students are being asked to abandon a concept that has seemed to them to be successful in explaining a range of experiences. (Strike & Posner, 1992, p. 154.)

However, Pintrich, Marx and Boyle (1993) believe that the conceptual ecology metaphor is limited in its ability to explain the tenacity of alternative conceptions, as in their view the model is too rational and pays too little attention to students' motivation. They contend that the assumption that students approach their classroom learning with a rational goal of making sense of the information they receive may be simplistic, as students may have many social goals in the classroom which short-circuit any in-depth intellectual engagement. They also agree with other authors (Dykstra, Boyle, & Monarch, 1992; Smith, 1991; Villani 1992) who point out that even when students did focus on academic achievement, this did not necessarily mean their aim was to solve intellectual problems. Their general objective, which is usually to receive official certification of their competence in academic activities, can often be achieved through behaviour such as 'rote learning'. This contrasts with the teacher's objective which is meaningful learning on the part of the students. Like Solomon (1983), Villani believes that adherence to the life-worldview should come as no surprise and ought to be considered normal and rational behaviour:

> The spontaneous way of seeing phenomena was constructed over a long period of time, and is the result of many personal interactions. It provides a way of directly dealing with many natural phenomena, of speaking and communicating in an intelligible way with the social community, and of predicting qualitatively what to do in a new situation. Consequently, for students it is a most useful means of effectively solving everyday problems. For this reason students accept spontaneous knowledge and believe that its method of reasoning is the most efficient for treating the natural world. (Villani, 1992, p. 231)

Villani goes on to state that many students fall into the habit of pursuing academic knowledge only when the teacher proposes clearly stated problems and continue to use their spontaneous knowledge in all other cases. Concrete 'acceptance' of academic knowledge only really begins when the number and importance of the problems it solves becomes significantly greater than can be solved using spontaneous knowledge.

Driver, Leach, Scott and Wood-Robinson (1994) point out that students' tendency to maintain their alternative conceptions is more prevalent in some areas of the curriculum than others. Newtonian mechanics and current electricity, they suggest, are two such areas, possibly because with these aspects of science much of the scientific view is counter-intuitive, and students' everyday experiences reinforce their prior conceptions. Taylor (1994) agrees, and states that from an everyday perspective, to maintain a constant speed when riding a bicycle on a level surface in a straight line direction requires a constant force to be applied to the pedals. However, from a Newtonian perspective, a constant speed in a straight line direction results from a balancing of opposing forces (surface friction versus driving force of legs) that results in a zero net force. In other words to ride a bicycle at a constant speed in a Newtonian world (of no friction) would require no force to be applied to the pedals. Clearly this scientific view is counter-intuitive, and thus Driver et al. (1994) argue for extended curriculum time and carefully researched instruction specifically for such topics, if any change in this situation is to be achieved.

2.3.3 Conceptual progression in science

Most of the studies on student conceptions have been 'one-off snapshots' that is, investigating students' conceptions at one particular point in time. These studies provide little evidence as to how students' understanding of science develops with age. However, cross-age studies which probe the scientific understanding of large cohorts of students at different age intervals give more insight into conceptual development. The findings of a number of such cross-age studies (e.g., Brook et al. 1989; Guesne, 1985; Holding, 1987; Leach, Driver, Scott, & Wood-Robinson, 1995) have indicated that students' views are not idiosyncratic in domains that have been systematically studied, with similar forms of reasoning being reported in different studies. This has prompted Driver et al. (1994) to suggest that:

> learning within a particular domain can be characterised in terms of progress through a sequence of conceptualisations which portray significant steps in the way knowledge within a given domain is represented. (p. 85)

This sequence of conceptualisation they call a 'conceptual trajectory', and within many specific domains in science, characteristic conceptual trajectories in students' reasoning can be identified. Thus cross-age studies on light (Andersson & Karrquist, 1983; Boyes & Stanisstreet, 1991; Guesne, 1985) suggest that young children tend not to represent light existing in space. Later children begin using the idea of a 'bath of light' which illuminates objects. This is followed by the realisation that light travels from a source and does not simply exist in space. The final development in the conceptual trajectory for light is the notion that non-luminous objects can be seen because light is reflected off them into the eye.

Similarities have also been identified in cross-cultural studies of conceptual trajectories (Mali & Howe, 1979; Ramorogo & Wood-Robinson, 1995; Vosnaidou & Brewer, 1992).

Conceptual trajectories cannot be used to predict how an individual student's reasoning evolves as they are not derived from longitudinal studies of individuals but rather cross-age studies of large groups of students. However, insofar as they reveal that commonalties exist in the way in which children's conceptual development occurs in particular domains of science, these trajectories may prove to be of value in informing, planning and sequencing the curriculum and related instructional materials.

The research findings on students' alternative conceptions in science help to explain why the teaching of science is often not as successful as anticipated. What students learn from lessons and activities depends not only on the nature of the tasks, but also on the knowledge schemes that students bring to these tasks (Driver & Bell, 1986). Tasker (1981) suggests that students' knowledge structures, against which learning experiences are considered, are often not those assumed by the teacher, and thus the understandings developed from the outcomes of experimental work are frequently not those anticipated.

2.3.4 Implications for teaching

From the evidence presented in the preceding sections, it appears that the issue of students' prior knowledge must have profound implications for the teaching of science. Some of these, such as the time allocated to particularly difficult conceptual areas, and the sequencing of teaching materials have already been touched on briefly. Other authors (e.g., Pope & Gilbert, 1983) point to the importance of relevance and claim that many students are turned off science because of the perceived gap between the content of science lessons and their own everyday experiences.

Gilbert et al. (1982) have proposed five possible outcomes which can result from the interaction between the teacher's view of science and the student's existing knowledge:

1. *The Undisturbed Children's Science Outcome* - the student's viewpoint is essentially unaltered despite formal teaching.

2. *The Two Perspectives Outcome* - the student rejects the teacher's science as an acceptable way to view the world, but considers it as something to be learned perhaps for examination purposes.

3. *The Reinforced Outcome* - the dominance of the student's prior understanding is reinforced, because the student has misinterpreted what the teacher means, and now believes the scientific viewpoint underpins his/her thinking.

4. *The Mixed Outcome* - the student holds ideas that are not integrated and may be self-contradictory. In this outcome the learner's views are an amalgam of student's science views and teacher's views.

5. *The Unified Scientific Outcome* - the learner obtains a coherent scientific perspective which he/she understands, appreciates and can relate to the environment in which he/she lives.

Driver (1989) has attempted to identify aspects of pedagogy which take account of students' current understanding while encouraging the development of conventional science ideas. These include providing opportunities for students to talk through their existing ideas thus allowing further learning as the students clarify and compare ideas. Teachers can listen to students' contributions in a diagnostic way which means going beyond an immediate judgement of whether the contribution is 'right' or 'wrong' and attempting to understand how the student comes to the answer that is given. Appropriate experiences including discrepant events can be provided to help students see the limitation of their own notions and assist in the restructuring of ideas. Driver believes that in this way students, if motivated, can bring new ideas and prior experiences together to take their thinking forward.

There is now a belief that to develop in students the scientific viewpoint is too difficult a task (Gilbert et al. 1982) and perhaps an unnecessary one (Duit, 1994), and that a more modest and manageable goal is to make learners aware that there is another viewpoint, the scientific viewpoint. Thus while the students' conceptions may be quite valuable in certain situations and daily life contexts, there are other contexts in which science conceptions are the only ones that provide fruitful understanding. For example, as Driver et al. (1994) point out, in everyday life a continuous view of matter is usually adequate in dealing with the properties and behaviour of solid substances, but in a different context, such as a chemist dealing with a synthesis reaction, it might be more useful to think in terms of atoms.

This section examined some of the more important characteristics of students' alternative conceptions to come out of the vast amount of research in this field, and concluded briefly by discussing the implications for the teaching of science, an issue which will be dealt with more fully in a later section on conceptual change. The section which follows reviews the major studies specific to primary teachers' understanding of science.

2.4 Studies on primary school teachers' understanding of science

It was not until the mid 1980s that similar studies to those on children's understanding of science were undertaken with primary school teachers. This is perhaps surprising, as the teaching of science in the primary grades has been perceived as a persistent problem (Henry, 1947; Symington, 1974; Helgeson, Blosser, & Howe, 1977). For example, in 1978, in the United Kingdom, the Department of Education and Science was explicit about the importance of primary teachers' scientific knowledge:

> The most severe obstacle to the improvement of science in the primary school is that many existing teachers lack a working knowledge of elementary science appropriate to children of this age (DES, 1978, par 5.83)

Because science is a discipline that builds on previous knowledge, the primary school plays an important role in children's education. If students are not exposed to good quality science education in their early years of schooling, they will be at a significant disadvantage later. However, the conceptual level at which primary teachers need to understand science in order to teach it to young children is somewhat contentious. Many teachers think it is only necessary to keep one step ahead of their students (Kruger & Summers, 1989). Yet it is difficult to see how teachers can give children appropriate experiences which enable them to acquire a progressive understanding of science concepts unless the teachers understand the concepts they are attempting to teach and know what lies at the end of this conceptual development. In fact Wittaker (1980) maintains that many primary teachers are all too often unable to help children extend their thinking because the teachers themselves are unable to make a connection between their recollection of a theory and the children's practical activities.

According to Russell, Bell, McGuigan, Qualter, Quinn and Schilling (1992), the knowledge and understanding required to teach science at the primary level is not general knowledge or 'common sense', but very specific knowledge of scientific concepts; it is not knowledge that every individual picks up along the way, for survival or out of casual interest. While it is acknowledged that primary teachers may not need the depth of conceptual knowledge of the secondary teacher, some understanding of the substantive structure of science would greatly assist primary teachers to help children perform comparing, pattern-finding, hypothesis generation and question-raising investigations (Harlen, 1985).

However, studies on primary teachers' understanding of science concepts have indicated that many of the ideas they hold are not in accord with the generally accepted scientific viewpoint (e.g., Kruger & Summers, 1988; Smith & Peacock, 1992). In some cases the teachers' beliefs have been found to share features of children's views of scientific phenomena (e.g., Apelman, 1984; Smith, 1987). Smith and Neale (1989) suggest that it may be useful to consider primary level teachers as adult novices in some, if not all, of the science areas they teach. These findings appear to be true not only for a number of science domains (Lenton & McNeil, 1991a, 1991b; Summers & Kruger, 1992; Summers & Mant, 1995), but also across a range of different countries (Fensham, 1988; Summers, 1994). In fact Osborne and Wittrock (1983) commented that, in general, the teaching of primary science involves the presentation of a mixture of the teacher's own everyday views and scientific ideas quoted from the text book.

2.4.1 Studies from Western countries

One of the earliest studies involving primary teachers was undertaken in the United States by Lawrenz (1986) who carried out a comprehensive baseline study on the existing state of knowledge of the physical sciences amongst 333 primary school teachers from Arizona. The teachers were participating in a physical science in-service training program, and were presented with a 31 item, multiple-choice Physical Science Test (PST). The results of the PST revealed many misconceptions. Specifically, it was found that 24% of the sample believed that adding a gas to something would make it lighter, while 28% indicated that adding one pound of salt to 20 pounds of water would result in a solution weighing 20 pounds rather than 21 pounds. Fifteen percent thought the final weight was unpredictable.

Lawrenz concluded that many teachers based their answers perhaps on life experiences in which they had seen balloons float when inflated and noted that adding salt to water did not appreciably change the volume. The findings supported the belief that primary school teachers did not have adequate background knowledge in the physical sciences. Lawrenz made the point that this was despite the teachers in the sample having strong educational backgrounds (47% of the participants held Masters degrees). However, this would seem to have little relevance if these degrees were not related to science. Nevertheless, there appeared to be a major need for primary school teachers to receive in-service training in the physical sciences, in which, according to Lawrenz, they would be given opportunities to make predictions based on their own belief patterns, and then be presented with concrete experiences which conflicted with these misconceptions so that they would be forced to reassess their beliefs.

A series of further studies in the USA, (Bendall, Goldberg, & Galili, 1993; Feher & Rice, 1987; Galili, Bendall, & Goldberg, 1993; Smith & Neale, 1989) have explored primary teachers' and prospective teachers' understanding of the physics of light and shadows. Each study revealed weak content knowledge in this domain, with 20% of the subjects in the initial study attributing the presence of shadows to something other than the absence of light (reified shadows). The study by Galili et al. (1993) revealed that a lack of understanding of the idea that light from each point on a source goes out in all directions was the root of many students' difficulties in understanding image formation.

Concerns have also been raised about primary level science in the United Kingdom where the introduction of a National Curriculum in science in the late 1980s has seen a shift in the thinking behind the teaching of primary science, from an emphasis on the process skills of science to an approach that identifies a greater role for content. Thus, primary school teachers in the UK now find themselves teaching more of the theory of such concepts as force, energy and states of matter. Recent research by the Primary School Teachers and Science Project (PSTS) has resulted in a series of articles (e.g., Summers & Kruger, 1994; PSTS, 1993) in which it is clearly demonstrated that there was a severe mismatch between primary school teachers' understanding of science concepts and the demands of the new National Curriculum for science.

In a two year study, the PSTS research group initially used interviews-about-events (Osborne & Gilbert, 1980a) and interviews-about-instances (Osborne & Gilbert, 1980b) to investigate the views of force, energy and materials held by 20 primary teachers from three different Local Education Authorities in England. The findings of the interviews revealed that, amongst other things, few of the teachers had a Newtonian conception of force and motion, with ideas related to impetus and dissipation being common, while about one third of the teachers thought gravity was a force produced by the atmosphere (Kruger, Summers & Palacio, 1990a). Similarly, few of the group incorporated the notion of 'molecules' into their conceptual models of matter (Kruger & Summers, 1989) and several teachers did not consider that energy was a term applicable to objects if they where inanimate, whether they were moving (toboggans) or stationary (rocks) (Kruger, 1990). A more extensive questionnaire survey of 159 primary school teachers revealed that misconceptions about force and energy were prevalent in the sample population (Kruger, Palacio, & Summers, 1990, 1992).

It could be argued that, in some instances, these authors were being over critical of the primary teachers' lack of content knowledge. For example, it is hardly surprising that primary teachers do not incorporate the concept of latent heat when explaining changes of phase in materials as this concept is not taught until the final years of high school. Nevertheless, some of the alternative conceptions revealed by the study did give cause for concern.

Carré (1993) reported similar findings in the UK, after testing 49 pre-service primary teachers with an instrument developed by Harlen, Black and Johnson (1981). This instrument was originally designed to determine the understanding of children at age 11. The student teachers, as a group, performed less well than the most 'able' 11-year-olds (i.e., the top 20%), and Carré concluded from their written responses that:

> Given that all the questions were developed within an everyday context to represent just the sort of world of science which primary children might wish to discuss, it would appear that many student-teachers would have difficulty doing so, within accepted adult science frameworks of understanding. (p. 26)

Kruger and Summers (1988) were able to classify teachers into four groups on the basis of their interview findings:

1. Teachers whose understanding of concepts was necessarily based on *life-world* beliefs. These teachers had received little or no education in physics during their schooling. Their explanations were based on imaginative theoretical constructions from their common-sense knowledge and personal experiences, and were of a superficial nature lacking internal rigour or consistency.

2. Teachers who had been exposed to the formal models and theories of physics during their schooling. These typically gave responses that were a hybrid of life-world knowledge and half remembered information from their school days.

3. Teachers who were similar to group (2) but when challenged on their understanding discarded the symbolic knowledge of their schooldays in favour of their intuitive beliefs.

4. Teachers whose interpretations were scientifically correct. Here the intuitive beliefs of the life-world seemed to be subordinated to those of the symbolic world of science.

The PSTS team has begun investigating other areas of science with groups of primary school teachers. In particular, the Earth and the universe (Mant & Summers, 1993; Summers & Mant, 1995) and certain biological concepts (Lenton & McNeil, 1991a, 1991b). This work has indicated that lack of knowledge and the presence of misconceptions is not just restricted to the more 'traditionally difficult' areas of science. In the studies dealing with the Earth's place in the universe, widespread lack of knowledge and understanding of phenomena such as day and night, and the behaviour of the Moon were revealed (Summers, 1994). This is consistent with the findings of previous studies which showed that primary school teachers' understanding of scientific concepts may be tenuous even in areas where they feel confident, such as natural sciences. For example, in the course of a survey about children's ideas about the concept of 'animal', Osborne and Freyberg (1985) found that only 86% of experienced primary teachers said that spiders or worms were animals.

The PSTS study has also provided some interesting insights into the features of primary teachers' scientific views. Although teachers share many of the same naive ideas of children, their ideas are often more varied and complex, perhaps reflecting wider experience of the world and considerably greater powers of expression (Kruger & Summers, 1988). There is also a difference in terms of tenacity. Whereas children tend to adhere to their alternative conceptions in spite of any inconsistencies, primary teachers have been found to express a strong desire to resolve those anomalies in their thinking once the anomalies have been exposed. In fact, some teachers felt that the experience of being interviewed, although unpleasant, was useful, as it had caused them to think more deeply about their own ideas and, in many cases, helped them to modify the ideas during the course of the interview (Kruger & Summers, 1988). Others claimed that their overall perceptions of their needs had changed as a result of the interviews (Kruger, Summers, & Palacio, 1990a).

This motivational difference has also been reported by Gunstone, Champagne and Klopfer (1981) and Champagne, Gunstone and Klopfer (1985a), who found that young high school students showed less inclination to change their ideas in physics than did trainee teachers. They speculated that because the trainees were soon to teach the concepts themselves, the advantages to them of the intellectual struggle needed to understand what was being tackled was much greater than the advantages perceived by the high school students.

Problems of scientific understanding amongst primary school teachers are not unique to the UK within Europe. Noce, Torosantucci and Vicentini (1988) found widespread misunderstanding of gravity, and the Moon among a sample of 53 Italian primary school teachers. Specifically, they noted that the majority of the sample group used alternative schemes, rather than the Newtonian scheme to explain phenomena relating to the force of gravity. These findings help confirm the view of Vicentini-Mossori (1980) who pointed out that Italian primary school teachers shared a common sense scientific culture with children and their parents.

Other Western cultures reveal a similar situation. Webb (1992) reported that Australian primary school teachers held views of electric current which were similar to those of 11-year- old students in Australia and New Zealand, with a significant proportion believing, for example, that electric current will flow in both directions at one time within a circuit.

More recently, Ginns and Watters (1995) investigated the intuitive scientific ideas and understanding of 321 Australian pre-service primary teacher education students enrolled in the second year of a three year program. The students completed a series of open-ended questions about the concepts of floating and sinking, the nature of matter, air pressure and its effects, and the balance beam. The findings of the study were consistent with those of the previous studies, as many of the prospective elementary teachers demonstrated a range of inaccurate scientific concepts. They also provided indirect evidence that many of the pre-service teachers were not reasoning at a level required to visualise and construct the mental models needed to solve the problems presented, thus indicating that they had not reached the 'formal reasoning stage of development in science.'

The same authors (Watters & Ginns, 1994a) have demonstrated that although primary teachers have been reported as expressing a desire to revise their thinking about science concepts (Kruger, Summers, & Palacio, 1990a), the tenacity of intuitive ideas can still remain a problem. Pre-service primary school teachers were shown to hold tenaciously to an intuitive impetus theory on a projectile motion problem even after they had been presented with discrepant video evidence in which they were shown the trajectory of a projectile frame by frame.

2.4.2 Studies from developing countries

All of the studies above report research undertaken in Western countries. Very little work has been undertaken in developing countries where, in general, societies are less technological. However, there have been some exceptions. In an investigation of the ideas held by African primary school teachers about air and air pressure, Rollnick and Rutherford (1990) conducted a series of interviews and tests with primary school teacher trainees in Swaziland. Using information from the interviews, the authors were able to draw up a Conceptual Profile Inventory (CPI) for air pressure. This inventory was a systematic list of concepts held by those interviewed, integrated with the accepted scientific conceptions. In general, there was found to be close agreement between the Swazi sample and the literature on misconceptions based on studies carried out among pupils in developed countries.

Webb (1992) in South Africa and Tan Boon Te (1994) in Brunei have demonstrated that pre-service and in-service primary teachers hold views on electricity which are also similar to those reported for children in Western countries. Finally, although research of this kind in the islands of the Pacific is extremely limited, some has been undertaken. Work by Tulip and Lucas (1993) with lecturers at a teacher training establishment in Papua New Guinea revealed that the lecturers were not very confident in their own knowledge about the nature of electricity, despite having to cover this topic with prospective teachers, while a recent survey of elementary teachers in the Republic of the Marshall Islands (RMI) (Sigrah, Rilometo & Albert, 1997) revealed that 43.8% had either elementary level or no background in science, with a further 18% with only a high school background. As a result science education in the elementary sector of RMI is considered problematic. Furthermore, Marshallese nationals tend to avoid science-related careers, with only one Marshallese national teaching science in the public secondary school system.

2.4.3 Substantive content and pedagogical content knowledge

Having established that primary teachers often have weak scientific knowledge with many alternative conceptions, it is important to identify the kinds of knowledge required for successful science teaching at the primary level. Shulman (1986, 1987) makes the significant distinction between content knowledge and pedagogical content knowledge and argues that both are important. Content knowledge or substantive content knowledge (Smith & Neale, 1989), according to Shulman, should incorporate not only a knowledge of facts, concepts and theories, but also the relationships between them. In other words they should be organised by a conceptual model of the domain. Although the importance of substantive content knowledge has already been mentioned, it is worth further comment in this context.

Grossman, Wilson and Shulman (1989) argue that, without the essential base of subject matter knowledge, teachers are simply unable to produce effective instruction. Certainly, Anderson and Smith, (1985) believe that in science teaching, and especially in conceptual change teaching, it is critical that the teacher be able to present and explain the scientific model clearly and to contrast it with student models. Yet, in some instances, teachers failed to identify incorrect conceptions in student responses. As a result of weaknesses in their own disciplinary knowledge, no problem appeared to exist (Hewson & Hewson, 1987; Tomasini & Balandi, 1988). In other cases teachers were observed whose substantive content knowledge was insufficient to clear up children's confusion during science lessons (Roth, Anderson, & Smith, 1986), while Anderson and Smith (1983) commented that even teachers who could state scientific principles correctly in lessons sometimes made mistakes when trying to explain phenomena. In the United Kingdom, Bennett and Turner-Bisset (1993) reported that a lack of subject knowledge appeared to result in less intellectual input to lessons on the part of student primary teachers, and more management during teaching.

According to Russell et al. (1992), many primary teachers, who describe themselves as having sufficient scientific knowledge for the level they had to teach, or who mentioned that they had some science qualifications, still expressed doubts about their ability to teach science effectively. This suggests that teachers not only need correct content knowledge, but also the ability and confidence to use that knowledge to lead discussions, provide examples and explanations, and generate problem-solving applications (Garnett & Tobin, 1988; Smith & Neale, 1989).

Thus teachers' ability to provide children with appropriate learning experiences appears to be as important as their substantive content knowledge. It is knowledge of strategies which helps make new information more readily accessible. Shulman (1986, 1987) refers to such knowledge as pedagogical content knowledge. This should include, knowledge of students' typical alternative conceptions, how these compare with the recognised scientific view, and the usual developmental path along which students progress. It is the teacher's task to help students examine the naive theories that characterise their own science and entertain the ideas reflected in scientists' science (Pope & Gilbert, 1983; Shymansky, Woodworth, Norman, Dunkhase, Matthews, & Chin-Tang, 1993; Smith & Neale, 1989). However, in primary science, teachers are rarely aware of students' alternative conceptions (Hollon & Anderson, 1986) or else they tend to ignore them or assume that they can be easily changed (Hollon & Anderson, 1987).

Teachers also need to be aware of a range of teaching strategies which enable students to gain a progressive understanding of science concepts. These strategies include eliciting students' preconceptions, providing discrepant events, encouraging debate and discussion about evidence and clearly presenting alternative scientific explanations. Such strategies are rarely used in the teaching of science at the primary level (Anderson & Smith, 1983; Neale, 1987; Smith & Lott, 1983).

Finally, teachers should be able to provide their students with appropriate examples, explanations, metaphors, analogies and other representations. Smith & Sendelbach (1982) have suggested that teachers with a limited content knowledge may use metaphors or analogies that are conceptually misleading for students, while Grossman et al. (1989) believe that teachers with weak pedagogical knowledge run the risk of misrepresenting the subject matter they teach.

Although this study confines itself largely to determining the substantive science content knowledge of Fiji pre-service primary teachers, it is important to acknowledge the relationship between both types of knowledge (substantive and pedagogical) and the role they play in the effective representation of science at the primary level. McDiarmid, Ball and Anderson (1989) point to this relationship by citing evidence that teachers' subject matter understanding is critical for their capacity to pose questions, select tasks, evaluate their students' understanding and make curricular decisions. In fact, Summers (1994) has used the term curricular expertise to embrace both types of knowledge which he, like Morrison (1989), believes are crucial determinants of teaching performance.

The evidence from the preceding section may beg the question, should primary science be taught by subject specialists? Russell et al. (1992) believe this would be an unnecessary step, as the science knowledge required to teach at the primary level is not so great as to be beyond the range of generalist teachers. Nevertheless, they stress that this supposes they are given the means and the opportunity through adequate training. There is also evidence from a study by Zuzovsky, Tamir and Chen (1989) which indicates that using specialist science teachers at the primary level has no effect on student achievement. Interestingly, these authors claimed that almost all the teachers in the sample, both generalists and specialists, had been 'well trained.' Although they do not specify what constitutes being well trained, their findings seem to lend support to the views of Russell et al.(1992) that, given appropriate training, generalist teachers should be able to cope with the challenges of teaching primary level science.

In summary, it would appear that there is ample evidence that primary teachers generally have weak subject or substantive science knowledge. This, in conjunction with limited pedagogical content knowledge related to science teaching, may impact adversely on their students' conceptual development in the discipline. This trend shows up in a number of countries both in the Western and the developing world and manifests itself in a large number of domains in science, even those with which teachers feel confident.

The effect of this state of affairs on teachers' confidence and general attitude to the discipline of science can be quite marked. The section which follows examines this in more detail.

2.5 Primary teachers' attitude to science and science teaching

The importance of primary teachers having a sound understanding of science concepts can not be over-emphasised, not least because many of the alternative conceptions found in young children may well stem from their teachers (Rollnick & Rutherford, 1990), but also because teachers' conceptual understanding of the subject matter may affect their confidence, their attitude to science and their style of teaching (Duschl, 1983; Franz & Enochs, 1982; Tilgner, 1990; Wier, 1987). In certain instances, the effect on confidence may be so extreme that primary level teachers avoid science altogether. This was reported in the UK in 1978 when the DES (1978) observed that teachers:

> ...lack a working knowledge of elementary science appropriate to children of this age. This results in some teachers being so short of confidence in their own abilities that they make no attempt to include science in the curriculum. (p. 62)

Anecdotal evidence from the study by Smith and Neale (1989) showed this to be true for the USA as well. Teachers admitted that they avoided teaching science, and physics in particular, because of their own lack of knowledge.

Science anxiety appears to be widespread amongst those primary level teachers for whom the teaching of the discipline is compulsory. Kruger et al. (1990b) report a number of feelings expressed by primary teachers about teaching science in extracts from informal, unstructured, interviews:

> *Feelings of Anxiety* - I feel very frightened about doing science in the classroom....
>
> *Feelings of Inadequacy* - I feel I know nothing - totally inadequate...and in that I feel inadequate to do it I would rather walk from it.
>
> *An Awareness of Shortcomings* - I was very, very aware of my lack of knowledge. I was dealing with words which I may not have used correctly. (p. 140)

Similar negative feelings have been noted by Summers (1992) who reports comments from a questionnaire survey of primary teachers' views on teaching science such as:

> Always avoided science and felt totally insecure...Not sure what I was doing...Was confused and could not see how to help children...Would like to have improved my own understanding first. (p.36)

In a major study of primary teachers' self-perceptions, the Leverhulme Primary Project (Bennett, Wragg, Carré, & Carter, 1992; Carré, & Carter, 1990; Wragg, Bennett, & Carré, 1989), has investigated primary teachers' perceived competence to implement the National Curriculum in UK. In that study, the research team have attempted to quantify primary teachers' self perceptions of their ability to teach individual disciplines. In all, 901 primary level teachers from 152 schools responded to a questionnaire in which they were asked to score their perceived competency in various subject areas, according to the following four point scale:

1. = Yes, I feel competent with my existing knowledge and skills.

2. = Yes, I feel competent with some help from colleagues.

3. = Maybe, I'd feel competent with in-service help from colleagues.

4. = No, I feel I would not be competent without substantial in-service support.

Only 34% of the sample felt independently competent (scale 1) with their own knowledge and their ability to help children achieve in science. This compares with 81% and 68% who felt independently competent in English and Mathematics respectively. Along with science these two subjects are the core components of the National Curriculum in the UK. Overall, science was ranked 8th out of 10 subjects, with only music and design and technology (the latter having a strong scientific component) ranking lower.

As part of this overall project, Carré and Carter (1990) gave special attention to primary teachers' attitudes to science, with difficulty indices being computed for individual statements of attainment within the science curriculum. For most of the statements, fewer than half the teachers in the sample felt competent with their existing subject knowledge, with the greatest difficulty perceived with physical science topics, such as electricity, light and forces. Of particular concern were responses to statements about scientific method such as 'Identifying variables to be controlled in 'fair-testing', 'Critically examining investigations' and 'Suggesting questions for testing', which all attracted low levels of perceived competence with about 60% of teachers indicating they needed help. Carré and Carter concluded that the introduction of the National Curriculum and the science component in particular, has caused personal anxiety amongst many teachers, with feelings of inadequacy being widespread.

Russell et al. (1992) also encountered low levels of perceived competence to teach science amongst UK primary teachers, with some teachers reporting a fear of transmitting wrong ideas and causing students 'irreparable damage.' These authors report:

> The problems teachers were facing were rooted in an image of themselves as not knowing; not knowing how to plan science, not knowing how to teach science and not knowing and understanding the science conceptually. Inevitably these responses affected classroom practice. Some teachers were reluctant to engage with the science concepts, relying heavily on the development of process skills. Others adopted a didactic approach, transmitting specific facts; in these lessons there was little deviation from the lesson plan. This strategy would ensure there was no confusion in the message transmitted and avoided any discussion in which the teacher's own understanding might be challenged. (p. 136)

The adoption of a didactic style of teaching by teachers unfamiliar with science or insecure about their knowledge of the subject has been widely reported (e.g., Cronin-Jones 1991; Lee, 1995; Symington, 1980). Hacker and Rowe (1985), who observed teachers teaching a range of disciplines, found that didactic or informational approaches were twice as likely to be encountered when observing teachers teaching outside their specialist discipline area.

A particular characteristic of the didactic approach adopted by some teachers is a tendency to turn almost exclusively to science textbooks in order to execute their science instruction (Rutherford, 1987; Tilgner, 1990). Mant and Summers (1993) have also reported what they refer to as primary teachers' misplaced trust in the ability of existing resources to meet their needs in science. One teacher interviewed expressed the view:

> ...as long as I had access to resources that would give children that information...I think that would be adequate...But the important thing for the teacher is to know where to go to get the answers if they don't know about it, and where to direct the children so that there are adequate resources in the school for that sort of eventuality. (p. 125)

There are problems associated with an over-dependence on text books or other resources. Vosnaidou (1991) has pointed out several ways in which texts can be misleading, including inaccurate explanations, a mismatch between diagrams and explanations and a confusing choice of language. Additionally, Anderson (1991) contends that, as a result of consumer demand, many textbooks provide academic work that consists primarily of relatively easy but ineffectual questions. He goes on to state that science, as represented in most textbooks, appears to be dull and disconnected and not something most children would want to find out about in their spare time. This contention seems to support the observation by Lazarowitz, Baird and Allman (1985), that over reliance on the text is one of the features identified as most unpopular by students taking science. Conversely, de Laat and Watters (1995) observed that primary teachers who felt confident about their ability to teach science, did not depend exclusively on their prescribed sourcebook, and attempted to integrate science teaching into other subject areas.

Recently, Harlen and Holroyd (1997) have listed a comprehensive series of six coping strategies employed by primary level teachers with low confidence in science teaching. They argue that some of these when regularly applied can have a severely limiting effect on children's learning.

Not surprisingly, the apprehension referred to above can manifest itself in a general dislike for and a lack of commitment to the teaching of science on the part of many primary teachers (Manning, Esler, & Baird, 1981; Mechling, 1983; Osborne, Biddulph, Freyberg, & Symington, 1982; Westerback, 1984). Manning et al. (1981) surveyed a total of 191 primary teachers in Florida, USA and asked them to rate their confidence to teach primary science competently. Only 19% rated their confidence as above average, while 32% rated their confidence as below average. When asked to rank their preference for teaching various subjects, more than 50% ranked science 4th or 5th out of five subjects, and perceived their role solely as dispensers of facts. Twenty-five percent indicated they spent no time at all teaching science.

Lucas and Dooley (1982) make the important distinction between teachers' attitudes to teaching science and their attitudes to science itself. They point to evidence which suggests that while negative attitudes to teaching can be modified and positive attitudes fostered, negative attitudes to science are more resistant to change. There is also evidence (Brophy, 1991; Carré, 1993) that teachers' beliefs about science and the teaching and learning of science may be important influences on classroom teaching. A positive attitude towards science is seen to be vital at the primary level. In fact, a number of authors agree that the students' own school experiences of science are powerful determinants of their future attitude to science and that having good teachers is conducive to becoming a good teacher oneself (Haladyna, Olsen, & Shaughnessy, 1983; Lucas & Dooley, 1982; Shrigley, 1974; Watters & Ginns, 1994b).

A dislike of science amongst primary teachers has also been reported by Tilgner (1990) who believes that little has changed over the past 20 years. Tilgner cites inadequate teacher background in science as one of the major obstacles to effective primary science and recommends that pre-service teacher education programs should provide a wide range of science content and practical experience for their students.

However, this view may be over-simplistic, as evidence for the impact that training can have on teachers' attitudes towards science and science teaching appears to be conflicting. Manning et al. (1981) claim that a highly significant relationship exists between teachers' preparation and their practices and attitudes towards science, with the number of science content and methods courses and in-service seminars teachers had attended correlating positively with the time they spent on science, their confidence levels, and their preference for teaching science. Lucas and Dooley (1982) and Ginns and Foster (1983) also report an improvement in students' attitudes towards science and science teaching after training. The latter authors, however, suggest that male and female students respond differently to different types of instruction. Males obtained higher positive gain scores for attitudes under a lecture approach, while females appeared to make greater positive gains when a topic approach to science was adopted, perhaps because females respond positively to a higher level of personal involvement in learning (Ginns & Foster, 1983).

Anecdotal evidence for the positive effect of in-service training comes from the studies by Smith and Neale (1989), Russell et al. (1992), and Summers and Kruger (1994). These authors have reported increased confidence in dealing with science on the part of teachers who have received training, with increased content knowledge translating into more appropriate and flexible usage in lessons.

Conversely, Carré's (1993) one year longitudinal study of 59 pre-service teachers in the UK revealed that, overall, attitudes towards science and the teaching of science changed little during the year. Similarly, Ginns, Watters, Tulip and Lucas (1995) found no significant enhancement of confidence to teach science amongst a group of pre-service teachers, even after the successful completion of coursework in science content knowledge and teaching methodology. These conflicting findings support the contention by Skamp (1989) and Smith (1997) that the relationship between discipline studies, attitudes towards science and science teaching, and confidence to teach science may not be straightforward.

What is not in doubt, however, given the considerable body of evidence in the literature, is that many primary teachers lack confidence in their ability to teach science. This may manifest itself in a highly directive style of teaching. Although this appears to be linked, in many cases, to teachers' level of understanding of science, the connection is neither simple nor conclusive. Furthermore the impact that training may have on this problem is contentious.

A number of authors (e.g., Appleton, 1995; Duschl, 1983; Kirkwood, Bearlin, & Hardy, 1989) see the nature and organisation of the training that teachers undertake as being crucial. Duschl (1983) points out that the amount of instruction student teachers receive in science is not the most important issue, rather it is the sequential presentation of material, as students are comfortable with clearly defined goals. He goes on to state that much of the apprehension primary teachers have towards science and the teaching of science may be attributed to conflicting pedagogies used in science courses. Appleton (1995) agrees with this view:

> ...science discipline knowledge needs to be taught in a way which will give students a more positive self image of themselves as teachers of science and technology. Teaching discipline knowledge without taking this goal into consideration may do more harm than good; students' self-perceptions may well remain largely negative, and even become more negative. (p. 366)

He suggests that the teaching strategies which have proved effective in generating positive changes in self perceptions tend to be time consuming, and need to be conducted in small group settings rather than large lectures. Thus what is gained in self-confidence is paid for by covering less content. This raises another important issue, namely that self-confidence should not be confused with competence in teaching science. As Appleton points out, unless students also increase their grasp of science content, it could be argued that they will remain incompetent to teach the subject.

Nevertheless most of the evidence cited points to the desirability of raising primary teachers' confidence, not least because, as de Laat and Watters (1995) suggest, more confident teachers are likely to be more innovative in their approach to science. However, the task of achieving this is not easy. Simply providing teachers with more discipline based courses may not be the answer. More attention needs to be given to the way the discipline is presented. This in turn may result in less content coverage. Getting the right balance between content and presentation of science appears to be a key issue for teacher educators.

Before going on to review the various types of intervention which have been designed to improve primary teachers' conceptual understanding of science, it is appropriate to look specifically at some studies relating to the understanding of Matter and Kinetic Theory, the topic which will form the basis of the research in this project.

2.6 Research into the understanding of *Matter and how it changes* and the application of Kinetic Theory to this domain of science

The essence of the kinetic molecular theory can be summarised in a single sentence: *Matter consists of tiny particles, called atoms and molecules, that are constantly in motion* (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993). This concept forms one of the central instructional goals of most junior high school science curricula (Nussbaum, 1985). This is hardly surprising, as a meaningful understanding of so many other topics in the physical, life and earth sciences depends on the ideas about the molecular constitution of matter. In fact without reference to a particle model it is impossible to explain the macroscopic properties of matter (Albanese & Vicentini (1997). As Driver et al. (1994) suggest:

> ...there are concepts which are central to students' scientific understanding in a wide range of topics and in such cases giving an appropriate amount of teaching time to them is educationally worthwhile. We would suggest that the conservation of mass and the particle theory of matter are examples of such topics. (p. 96)

Gabel (1993) has demonstrated, albeit with a small group, that improved understanding of Kinetic Theory helps students make connections in other areas of chemistry. Thus, because Kinetic Theory underpins so many other conceptual areas of science, it has been one of the more exhaustively studied topics for conceptual understanding.

Early work by Novick and Nussbaum (1978, 1981) in Israel and the USA respectively provided insight into the sorts of alternative conceptions students hold about matter. Specifically, they found that some students conceptualised matter as a continuous entity, while others viewed it as continuous but with embedded particles. As Renstrom, Andersson and Marton (1990) point out, anyone who views matter as being completely homogeneous cannot meaningfully deal with the problem of transition between different phases (e.g., from liquid to gas). For such individuals matter can only exist as it is. Similar problems arise if students attempt to apply a homogeneous model of matter when accounting for chemical reactions. Williamson and Abraham (1995) also believe that a lack of understanding of chemical concepts may be linked to students' inability to build complete mental models that visualise particulate behaviour.

This may explain why research studies consistently report that some students have great difficulty explaining the nature of substances and observable changes between substances (Bar & Travis, 1991; Osborne & Cosgrove, 1983; Russell, Harlen, & Watt, 1989; Stavy, 1988; Stavy & Stachel; 1985). Such problems are particularly true for gases which, in general, have no visible attributes available to children. Consequently, children have difficulty in conceiving gases as substances. Thus children commonly believe that gas has no weight, or that gas is lighter than the liquid or solid from which it was obtained (Stavy, 1988). Bar and Travis (1991) reported that children often explained evaporation in terms of a liquid simply disappearing or in some way penetrating a solid container. These findings are supported by the work of Russell et al. (1989) who further probed such ambiguous terms as 'disappeared' and 'vanished' and were able to confirm that children who used them meant that the liquid had ceased to exist. De Vos and Verdonk (1996) point out that even when students use a particulate model they may be convinced that providing each gas particle with a free will of its own is a simple way to explain why a gas escapes from a leaking container.

Problems of this nature are not exclusive to children's explanations of the gaseous phase. Stavy and Stachel (1985) reported that powders were misclassified by children of all ages and were referred to as liquids or as a separate group, while Driver (1985) found that students perceived a substance in a powdered form as having less mass than in a solid form.

Osborne and Cosgrove (1983) demonstrated that even after instruction the scientific terms used in describing changes of phase were often only superficially understood. Although students could use terms such as 'condensation' and 'evaporation' in the correct context, further questioning as to what was actually occurring produced a set of responses which indicated that even older students had no sound scientific concepts of these terms.

Andersson (1990) has reviewed many of the studies on students' conceptions of matter and its transformation. He believes that the dynamic picture of atoms and molecules in never ending motion in empty space may not be used by a significant number of students. A large proportion of students are able to use models 'compatible' with the conception that matter is continuous and static to account for changes of state, conservation of matter and even chemical transformations. Andersson identifies four such models; disappearance, displacement, modification and transmutation, which allow students to explain a range of phenomena while adhering to the everyday view of matter as continuous and static.

A recent study by Lee et al. (1993) has attempted to examine this issue in more depth. In a two year longitudinal study which involved fifteen 6th grade classes in the USA, these authors sought to gain greater insight into the conceptual frameworks the students used to explain the nature of matter and molecules. To achieve this they recorded students' explanations of various phenomena relating to matter and how it changes using paper-and-pencil tests and clinical interviews. The explanations provided were then analysed to determine whether the students could relate conceptions at a macroscopic level (i.e., concerning the nature of substances and their properties) to conceptions at a microscopic level (i.e., concerning molecules and their properties).

The results of this study indicated that, prior to instruction, most students rarely explained phenomena such as thermal expansion, change of state or dissolving in terms of a molecular or particulate model. After instruction however, many students still failed to use molecular language to explain dissolving, and although they did attempt molecular explanations of other phenomena such as thermal expansion, many students confused observable properties of substances with properties of molecules, and attributed changes in substances to changes in molecules themselves. For example:

> Student: It (metal ball) wouldn't go through the ring, because the molecules expanded and caused it to get bigger.
>
> Student: Well, warm air rises, and warming up the bottle is warming up the air molecules inside, and the molecules are rising up and going into the balloon. (p. 263)

This use of alternative particle ideas or mixed conceptions, such as particles expanding, and contracting, particles getting hot or particles melting, has also been described by Brook, Briggs and Driver, (1984). They found that one third of 15 year old students in a national survey in England attributed animistic behaviour to particles.

The results of the work by Lee et al. (1993) led the authors to conclude that teaching students about Kinetic Theory was very problematic.

> Most students did not understand the word *matter*, and their misunderstanding could not be resolved by a simple definition. To these students, gases such as air and helium seemed to have more in common with forms of energy such as heat and light than with solids and liquids...The idea that molecules are constantly in motion is also counterintuitive for many students: It seems to contradict their sensory observations (no motion is evident in many substances) and personal experiences (all moving objects eventually slow down and stop). (p. 267)

Mitchell and Gunstone (1984) agree and state that the achievement of a purely particulate model of matter is far more difficult than is generally assumed.

It is clearly vital for students to develop a particulate model of matter if they are to comprehend other areas of science. So a number of cross-age studies have been conducted in an attempt to map the conceptual development of the particle model in groups of children (e.g., Bar & Travis, 1991; Holding, 1987; Novick & Nussbaum, 1981), while others (e.g., Nussbaum & Novick, 1982a; Scott, 1992) have examined how ideas develop in individuals through time. Holding's study has indicated that reasoning about particles of matter tends to emerge in children's explanations at around ages 9-11, and McClelland (1982) has stated that quite young children can form a usable concept of molecules, and believes that the particulate nature of matter is a conceptual area which is accessible to children before the age of 11, enabling them to impose a coherent pattern on their environment. Other authors (Engel-Clough, Driver, & Wood-Robinson, 1987; Nussbaum, 1989) argue for the early introduction of key scientific concepts to students. Nussbaum believes that students' conceptual understanding lags behind the instructional sequence because learning is an evolutionary process.

> If conceptual change is an evolutionary process, then perhaps we should start the exposure to science ideas much earlier than is customary, in order to allow enough time for incubation and the development process. (p. 539)

Thus, the early introduction of a simple particle model of matter may be one way of developing, in children, a better long-term understanding of the key concepts of Kinetic Theory. Clearly such an approach is not possible if primary teachers also have problems conceptualising and applying molecular models (Kruger & Summers, 1989):

> A majority of teachers viewed the changes occurring in some of the materials in terms of a non-molecular particulate theory which was a mixture of intuitive beliefs and half remembered textbook science from their school days, sometimes with incorrect or imprecise use of scientific language. (p. 25)

These authors concluded that it was difficult to see how children could be correctly led along an experiential path leading to understanding of changes in materials and the associated role of energy unless the teacher guiding them had some deeper understanding of the process involved. Rollnick and Rutherford (1990) have also reported that pre-service primary teachers in Africa failed to use Kinetic Theory in their explanations of air pressure, despite having covered this topic in high school. However, these authors were not very explicit as to the alternative explanations given by the teachers, stating only that they were 'macro' type responses.

Given this situation, what strategies can be adopted to effect conceptual understanding in these teachers? The section which follows discusses some of the general strategies which can be employed in an attempt to achieve this goal and examines some actual interventions which have been conducted with primary level teachers.

2.7 Strategies to improve primary level teachers' conceptual understanding of science

As has been illustrated in the earlier sections, content knowledge in science is an area that has been a significant source of discomfort for primary teachers. In fact Osborne et al. (1982) regard lack of science knowledge as one of the main reasons why primary teachers are not, in general, committed to the teaching of science. This is despite a plethora of teaching materials available to primary teachers to upgrade their limited background knowledge (Perkes, 1975). However, the preceding evidence indicated that simply providing more materials or courses on science content may achieve little in terms of improving teachers' confidence or increasing their inclination to teach science. The pedagogy employed in such courses appears to be crucial in enabling teachers to access science knowledge (Appleton, 1995). This may be because learning science is usually not just a matter of adding information and making connections. Learners often have to be aware of and possibly change some of the ideas or conceptions they already hold in order to develop their scientific understanding further. Thus science courses for primary level teachers, whether pre-service or in-service, need to apply appropriate pedagogy.

The fundamental principle underlying most of the approaches to conceptual change stresses the importance of acknowledging the learner's existing ideas. This constructivist view of learning is now widely accepted by the science education community (Summers, 1992). There is, however, some disagreement amongst science educators as to how to proceed towards conceptual change once alternative conceptions have been established. Scott, Asoko and Driver (1992) have identified two main groupings of strategies aimed at promoting conceptual change and a better understanding of science. One grouping is based upon cognitive conflict and the resolution of conflicting perspectives. The second grouping is of strategies which build on learners' existing ideas and extend them. Duit (1994) has referred to these groupings as respectively representing discontinuous and continuous pathways towards conceptual change. Some of these strategies will be discussed below in general terms before examining the effect of their implementation in various studies conducted with groups of primary level teachers.

2.7.1 Strategies based upon cognitive conflict

Strategies for effecting conceptual change in the first of these groups are specifically designed to produce cognitive conflict through dissatisfaction with an existing conception. They largely appear to draw upon the Piagetian notion of accommodation (Piaget, 1964). One of the earliest models of conceptual change was proposed by Nussbaum and Novick (1982a, 1982b), and comprised four main elements:

1. Initial exposure of students' alternative conceptions through their response to an 'exposing event.'

2. Sharpening student awareness of their own and other students' alternative conceptions through discussion and debate.

3. Creating conceptual conflict by having students attempt to explain a discrepant event.

4. Encouraging and building cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

This model has been criticised by Hewson (1983) because it fails to identify the specific conditions necessary for conceptual change. Posner, Strike, Hewson and Gertzog (1982) and Hewson (1981) developed their own Conceptual Change Model (CCM), in which they explicitly addressed these conditions. They proposed four conditions which must be fulfilled if students were to make changes in their central concepts by integrating new conceptions with existing knowledge:

1. *There must be dissatisfaction with existing conceptions.* For example, if an existing conception fails to explain adequately a particular event.

2. *A new conception has to be intelligible.* The student must know what the new idea means, and be able to construct a representation of it.

3. *A new conception must be initially plausible.* The student must find the new conception to be potentially true or believable. That is, the student must be able to reconcile the new conception with his or her own prior conceptions.

4. *A new conception must be fruitful.* A new conception can be viewed as fruitful if it can solve previously unsolved problems, or if it gives better explanatory and predictive power than was previously possible.

These authors distinguish the process of *assimilation* or *conceptual capture,* when a new conception is inappropriately incorporated with existing conceptions, leading to non-meaningful learning, from that of *accommodation* or *conceptual exchange,* where a new conception appears to be in contradiction with existing conceptions. In the latter instance, the new conception's acceptance is blocked by the existing conceptions. In order for a person to accept it fully, the status of the blocking conceptions must be lowered before the status of the new conception can rise. Thus meaningful learning cannot occur until the everyday 'real-world knowledge' is appropriately changed and integrated with disciplinary knowledge. Thus, Posner et al. (1982) believe that teaching aimed at accommodation should provide anomalies which create the sort of cognitive conflict that prepares a student's conceptual ecology for an accommodation.

However, Hewson and Thorley (1989) argue that few of the studies which make reference to the implementation of the CCM truly incorporate the central aspect of the model: lowering of the status (in terms of intelligibility, plausibility and fruitfulness) of alternative conceptions and raising that of the target scientific conceptions. Rather, they believe that researchers often only make selective use of parts of the model, particularly considerations of the dissatisfaction condition and its relevance to discrepant events and cognitive conflict. They contend that more research is required on the use of the CCM as a learning model in the classroom. To this end they have identified *status comments* which they believe teachers can use to monitor the intelligibility, plausibility and fruitfulness of students' conceptions. For example, a statement such as 'I can understand sort of...but it is hard to imagine' implies that a conception is intelligible but not plausible to a student.

Using status comments to monitor conceptions, however, requires that students are honest about their understanding, and does not appear to allow for outcomes where students have interpreted teaching in such a way that it reinforces their alternative conceptions.

In response to criticism in the literature (e.g., Pintrich, Marx, & Boyle, 1993) the CCM has recently been revised (Strike & Posner, 1992) to take into consideration the view that it did not account for students' motivational beliefs and was based on the assumption that learners have well-articulated conceptions or alternative conceptions about most topics. Nevertheless the central tenet of the model has remained unchanged and as such it has continued to be criticised for having a narrowly conceived notion of knowledge and the role knowledge plays in an individual's life (Cobern, 1996b).

A number of other models have been developed to effect conceptual change (e.g., Champagne, Gunstone, & Klopfer, 1985b; Rowell & Dawson, 1985). All of these models are variations on the theme of eliciting students' ideas before contrasting them with evidence from other sources and resolving any differences which exist.

Guzzetti, Snyder, Glass and Gamas (1993) lend strong support to the use of such conflict strategies in effecting conceptual change in science. From their meta-analysis of eighty studies investigating various intervention strategies, these authors concluded:

> Based on accumulated statistical evidence from two disciplines, we found that instructional interventions designed to offend the intuitive conception were effective in promoting conceptual change. The format of the strategy seems irrelevant, provided the nature of the strategy includes cognitive conflict. (p. 149)

However, a number of criticisms have been levelled at conflict strategies. Karmiloff-Smith (1988) has questioned the effectiveness of discrepant events, which she believes students treat as anomalies and fault their own procedures rather than question their theory. This is in keeping with Chinn and Brewer's (1993) recent model of how individuals respond to anomalous or discrepant data which conflict with a pre-existing theory. These authors postulate seven possible outcomes. Six of these involved discounting the data in various ways in order to protect the pre-instructional theory, while only one response involves the acceptance of the data and a change of theory.

There is also a view that cognitive conflict as a strategy can impact negatively on learners' confidence, by appearing to devalue or even dismiss their intuitive ideas (Claxton, 1984). Taylor (1994) suggests that this results from the implicit acceptance, which pervades conceptual change research, of the superiority of the scientific view of the world and the concomitant inferiority of the learner's worldview. In some instances, this may even result in regression from correct to incorrect judgements (Stavy 1991). Dreyfus, Jungwirth and Eliovitch (1990) suggest that while successful students react enthusiastically to the challenge of cognitive conflict, it can cause less successful students to develop negative self-images. Driver (1989) also cautions that it is important not to insist upon conceptual change at the expense of the learners' confidence, arguing that maintaining the learners' confidence in themselves as capable of making sense of their experience is essential to the learning process.

This point is of particular significance when considering strategies for conceptual change with primary level teachers, given the wealth of evidence that, in general, their confidence in the area of science is extremely fragile. For this reason Osborne et al. (1982) propose that the training of primary level teachers should start with the ideas which children hold. In this way teachers are brought to a recognition of their own conceptions indirectly. This is much less threatening than exposing their own lack of understanding of science concepts, and is an approach which has been successfully exploited in a number of studies (Shymansky et al. 1993; Summers, 1992; Tulip & Lucas, 1993).

The work by Shymansky et al. (1993) is particularly interesting. Here, middle school teachers conducted research into their own students' preconceptions about a particular topic. The teachers then discussed the scientific merit of the students' conceptual frameworks with a science expert, and then developed instructional units which they later taught. Concept maps were constructed at three stages during this period to study changes in the teachers' scientific understanding. These maps were quantified and comparisons between the different stages indicated significant growth in the number of valid propositions expressed by teachers between the initial and final mappings.

Although conflict does arise in this approach, it is between the students' views and those of the expert. There is no direct 'attack' on the ideas of the teachers, and thus negative feelings are less likely to be generated. Also, the idea of teachers as researchers recognises the empowerment that occurs when teachers are allowed to reflect on their own experiences, experiment with new practices, and develop their own justifications for change.

2.7.2 Strategies based upon the development of learners' existing ideas

Strategies in the second group depend on identifying the learner's existing ideas and then extending these ideas towards the scientific viewpoint. Much of the work in this area involves the use of analogies to effect this extension. There has been some debate about what actually constitutes an analogy (Duit, 1991), but Glynn, Britton, Semrud-Clikeman and Muth (1989) suggest that an analogy 'is a correspondence in some respects between concepts, principles, or formulas which are otherwise dissimilar.' Treagust (1993) has simplified this, and states that an analogy is a process of identifying similarities between two concepts. One concept which is familiar, is referred to as the *analog* and the other concept which is unfamiliar, is called the *target*. Usually the target relates to the scientific concept. Analogies are believed to help learners by providing visualisation of abstract concepts, by helping compare similarities of the learners' real world with the new concepts, and by increasing learners' motivation (Duit, 1991).

There are now a number of instructional models which employ the use of analogies to help effect conceptual change, for example, Clement's (1987) Bridging model, Dupin and Joshua's (1989) Analogy Teaching model, Glynn's (1991) Teaching-With-Analogy-model, and Zeitoun's (1984) General Model of Analogy Teaching. Clement's Bridging Model is perhaps the best known of these examples and has been used to develop students' thinking in conceptually difficult areas of physics (Brown & Clement, 1989, 1992; Brown, 1992). Of particular interest is the notion of anchoring and bridging analogies. In this model, a target situation is one which includes a concept that students find difficult to accept, for example, the idea that a table exerts an upward force on a book (Figure 2.1 (C)). An anchoring example is a situation that is in some ways analogous to the target situation but has certain characteristics which students find intuitively acceptable, for example, students accept that a compressed spring does push up against one's hand (A). However, although they accept this, students may not accept that the target and anchoring situations are truly analogous. Thus, it is often helpful to use an intermediate third case, or bridging analogy, in this instance a heavy object on a flexible plank or foam layer, which acts as a bridge between the anchoring and target situations (B).

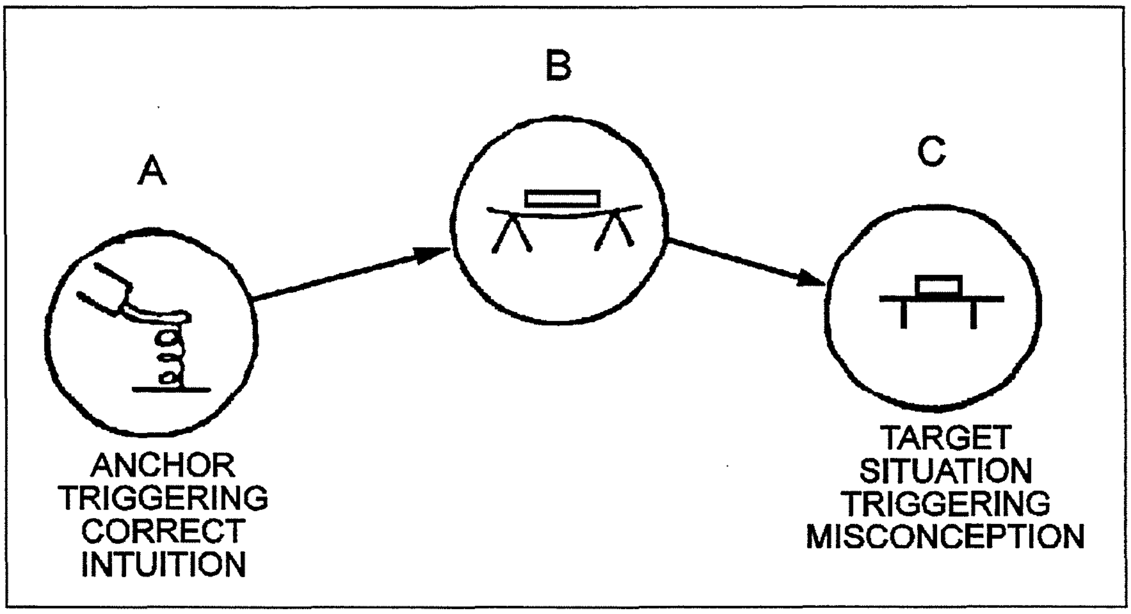


Figure 2.1. An example of an analogical model which includes the anchor (A), the target (C) and the bridging analogy (B). After Clement (1987).

Clement, Brown and Zietsman (1989) believe that although many students' preconceptions are detrimental to learning, there are others that are largely in agreement with physical theory and can act as anchoring conceptions. These workers have identified a number of group anchors which they believe may have useful application in conceptual change teaching.

One of the major advantages of using analogies to effect conceptual change is that this approach is potentially less detrimental to learners' confidence than a conflict approach. In fact Stavy (1991) believes that it is possible to avoid conflict altogether. She was able to overcome misconceptions about the conservation of mass during the evaporation of acetone, by using an analogous task involving the evaporation of iodine. In the study reported, students from grades five and six were divided into two groups. One group completed a task involving iodine evaporation where the gaseous iodine is visible as a coloured gas before attempting a similar task with acetone, which has an invisible gaseous phase. The second group used acetone first followed by iodine. It was found that performance in the acetone task was significantly better when it followed the iodine task. The intuitively understood, visually supported iodine task apparently served as an analogical example for the misunderstood acetone case. In Stavy's opinion, the students were not aware of any conflict between their ideas and the scientific view. From the students' point of view there was no misconception. This approach also finds favour with the views of Jung (1986), who believes that it is wiser not to elicit students' conceptions explicitly because they can be given higher status and thus be supported by discussing them.

The use of analogies does have certain constraints. Useful analogies are not always available for specific conceptions. Even when they are available their use does not always produce the intended effects. Some students take the analogy too far and are unable to separate it from the content being learnt, while others remember only the analogy and not the content under study (Treagust, 1993). Champagne et al., (1985a) report that the uncritical use of analogies may generate alternative conceptions, particularly when the learners are unfamiliar with the analogy (Gentner & Gentner, 1983). Nevertheless, there is now considerable research evidence (e.g., Summers, 1992; Treagust, Harrison, & Venville, 1993) to indicate that appropriate analogies can play an effective role in instruction for conceptual change. In fact, Treagust, Harrison, Venville and Dagher (1996) argue that for certain abstract scientific concepts such as refraction, analogy is not only desirable, but is often the only explanation available, and as such the potential of specific analogies to bring about conceptual change should be rigorously researched.

Niedderer (1987) has adopted a somewhat different approach to extending students' understanding. This involves discussing both the students' everyday beliefs about scientific phenomena and the scientific theory itself. There is no attempt to replace the former with the latter, but students are made conscious of both and learn science concepts by learning the difference between everyday thinking and scientific thinking. This approach seems to be gaining popularity as it appears to offer a less traumatic means of developing improved conceptual understanding than some of the other approaches discussed. Thus it may be more appropriate for use with groups of students with a wide range of ability and confidence.

Roth (1990) has also identified two groupings of conceptual change strategies which have continuous and discontinuous characteristics. In the main these are similar to the groupings described by Scott et al. (1992), as they comprise *Strategies to Engage Students in Conceptual Conflict* and *Strategies to Promote Student Construction of Meaning.* However, Roth's second grouping cites a greater variety of activities to help students construct meaning including the use of posters (Driver, 1987); cards (Roth, 1987; Smith & Anderson, 1987) and concept maps (Sieben, 1987). Roth also stresses how important it is for teachers to use discussion to guide student thinking and to help them construct meaningful understandings rather than quiz them on their mastery of scientific facts and definitions.

Whatever strategy is adopted in an attempt to promote conceptual change, Scott et al. (1992) believe that creating the correct learning environment is an important prerequisite:

> Firstly, the teacher needs to foster a *learning environment* which will be supportive of conceptual change learning. Such an environment would, for example, provide opportunities for discussion and consideration of alternative viewpoints and arguments. (p. 311)

2.7.3 Interventions aimed at improving primary teachers' conceptual understanding of science

Although there have been a number of studies into primary teachers' alternative conceptions in science, very little research has taken the next step and addressed the issue of conceptual change with these teachers. Thus most of the published research deals only with the identification of alternative conceptions.

However, Smith and Neale (1989) have addressed the issue of conceptual change in teachers' substantive content knowledge of the physics of light and shadows. During a four week intervention the teachers initially read and discussed research on children's alternative conceptions, and on teaching strategies to facilitate conceptual change. They were then engaged in a number of activities aimed at revealing their own alternative conceptions in this domain before being presented with a series of discrepant events which offered alternative views. Later the teachers taught small groups of children and conducted interviews to assess the children's understanding at the conclusion of the teaching sequence. The teachers also kept logbooks in which they reflected on their experiences. This intervention proved to be effective, with the authors reporting that teachers' substantive content knowledge did change, often substantially, over the training period.

This study has been criticised by Summers and Kruger (1994) as the sample was small (10) with detailed results being presented for only four teachers. However, this criticism appears to be unjustified as the study was predominantly qualitative in design. It used clinical interviews along with video evidence of the teachers' classroom teaching to provide detailed information on changes in the teachers' substantive content knowledge, pedagogical knowledge, and their orientation to science teaching and learning as a result of undertaking the course.

Bendall et al. (1993) have employed discrepant events to change prospective primary teachers' conceptions of light. These authors found that many of the teachers in their sample did not conceive that light from each point of a source could go out in all directions. They were able to use a clear bulb with a U-shaped filament to demonstrate uniform illumination, rather than the U-shaped pattern anticipated by the teachers.

Another study which adopted a cognitive conflict approach to conceptual change is reported by Rollnick and Rutherford (1993) and Rollnick (1988). In this research, an experimental group of Swaziland pre-service primary school teachers were exposed to materials presented in English and based on the Conceptual Change Model developed by Posner et al. (1982), while a control group was instructed using traditional methods. Two further groups were exposed to the same content but in this case a mixed language approach was adopted which involved the use of English and SiSwazi. This gave a total of four treatments within the experimental design.

The confirmatory tests used in the quantitative phase of this study revealed that the CCM materials were significantly superior when only English was used. The result of their use in conjunction with a mixed language approach was inconclusive. There was, however, a strong indication of the efficacy of the mixed language approach in changing certain alternative conceptions when used with the CCM materials. The authors believed that this could be because the use of mother tongue helps in the articulation of these alternative conceptions. They made specific comment on how the use of CCM materials promoted much student discussion in which they revealed their alternative conceptions about air and pressure. Rollnick and Rutherford (1993) argued that a strong case could be made for the use of a mixed language approach supported by materials in English only. However, given the rather inconclusive nature of their findings, it is difficult to see how such a recommendation is justified without the benefit of further research.

Success in improving primary teachers' conceptual understanding has also been claimed by researchers who avoided or placed less emphasis on the use of discrepant events and cognitive conflict. Kirkwood et al. (1989) employed metacognitive strategies such as the use of reflective diaries and concept mapping with primary level teachers in an in-service science course. These authors believe this approach helps the teachers focus on and take more responsibility for their own learning in science, and they provide evidence in the form of quotations from course participants to support their assertions of improved understanding and increased confidence. One feature of this course was that it required considerable time to implement, as it involved 14 two-hour workshops over a six month period.

In the UK, Summers and Kruger (1994) have developed in-service training materials which are designed to help primary teachers improve their understanding of physical science. These materials build on the findings of the research reported earlier (e.g., Kruger & Summers, 1988). The work has been influenced by the constructivist approach to adult learning proposed by Millar (1988), but is being used for the first time with UK primary school teachers who for the most part have little prior contact with the world of formal science. The development of these materials has been based on five key aspects of constructivism, which Summers (1992) suggests can be expressed as a series of needs:

1. To have knowledge of the teachers' existing understanding in the targeted conceptual area;

2. For teachers to become aware of their own views and uncertainties;

3. For teachers, at an appropriate time, to be confronted with the currently accepted scientific view;

4. To provide experiences that will help teachers accept the scientific view;

5. To encourage active, collaborative learning in which views are expressed, exchanged and developed through discussion and social interaction.

The basic strategy has been to build on the teachers' existing ideas through the use of analogy, which in this case is the bridging model developed by Clement (1987). However, an element of conflict has also been included in the approach as it was felt that the teachers should compare their own views with the expert (scientific) view of the concepts they were learning about. To make this as non-threatening as possible, teachers were brought to a recognition of their own conceptions indirectly through work they were required to do with children.

Metacognition, the understanding and control of one's own learning, was also incorporated into the overall strategy. This view, that primary school teachers need to develop some understanding of how they might learn science effectively, is shared by Gunstone and Northfield (1994). To assist in this process, teachers were introduced explicitly to constructivism, by including a constructivist model early in the training materials and discussing this with course participants as a model of both children's and their own learning.

Trials with 53 primary teachers using the 'force' and 'energy' in-service training materials have indicated that nearly all the teachers did improve their understanding considerably in both domains, and that this improvement was still evident 6-12 months later. Summers and Kruger (1994) have concluded from these trials that:

> A key feature of the results is that in-service training if well designed and based upon a current consensus of what constitutes good practice, can substantially improve primary teachers' understanding of science concepts. However, although greatly improved, the evidence supports the view that in many cases the scientific understanding achieved is likely to be partial and 'messy' with, for example, misconceptions co-existing alongside the scientific views and teachers unsure of their new knowledge. (p. 517)

As mentioned previously, Shymansky et al. (1993) obtained similar outcomes in their work with middle school teachers in the USA. These workers also report an overall improved scientific understanding on the part of their study group. Nevertheless, the concept maps generated by the teachers throughout the study indicated an ebb and flow of ideas in their conceptual frameworks. Shymansky and his team believed that the intermittent regressions which showed up in their study may have been points of disequilibrium that necessarily precede conceptual framework restructuring. They went on to state that apparent regressions in understanding should be expected when new ideas are being learned, and that they may actually be a signal that positive restructuring is imminent.

Thus, although it appears that improved conceptual understanding can be achieved with teachers by employing a number of different strategies, it seems unlikely that this will occur 'cleanly', with a complete rejection of an alternative conception and its replacement with the scientific view. As Gunstone and Northfield (1994) suggest:

> Conceptual change rarely involves complete abandonment of one notion in favour of another. Rather it often involves additions of new notions, retention of existing notions and acquisition of a sense of contexts in which the new notion is more appropriate. (p. 525)

There is also some doubt as to whether complete conceptual change, which implies the rejection of one view and its replacement with another, is really achievable. Rather, as mentioned previously, it may be more desirable to make learners aware that there is a scientific view, and attempt to ensure that they have an understanding of this view and the contexts in which it is applicable, rather than attempting to extinguish their prior conceptions. This approach, similar to that described by Niedderer (1987), will be discussed in more detail in the following section which examines the issue of teaching 'conventional' science in developing countries, a task which is arguably more difficult than that of teaching science in a Western context.

2.8 The cultural context of learning science

In the preceding sections there is substantial evidence to indicate that the teaching and learning of science, particularly that directed at conceptual change, has not been entirely successful in Western, technological societies. It may come as little surprise then, that the situation in the less technological societies found in many developing countries appears to be much worse. As mentioned previously, Pope and Gilbert (1983) suggest that many Western students are turned off science because of the perceived gap between the content of science lessons and their own experiences. This is despite many of these children being exposed to the products of highly advanced technology on a daily basis. For many children in developing countries this gap must inevitably be greater, as they are generally exposed to a less technological world, yet often follow science curricula which differ little from those in the West (Baker & Taylor, 1995; Hewson, 1988).

Science and technology are promoted as major contributors to national development (Dunne & Rennie, 1990). Consequently improved science education has been placed high on the agenda of tasks to be tackled in many developing countries (Kahn, 1990), although progress has often been limited. In fact, Elkana (1972, 1981) claims that the enormous investment in teaching science in developing countries has basically failed. This rather depressing view is echoed by other authors, for example, Lewin (1990a) who comments that although today far more children in developing countries study science than previously, the evidence suggests that the great majority do not master more than a small proportion of the goals set for them. Furthermore, Hewson (1988) describes how efforts to teach science in developing countries are often met with rote learning of strange concepts, mere copying and a general lack of understanding on the part of local students.

> For many students, (in southern Africa) learning science seemed to be like learning Latin. It involved the rote memorisation of strange concepts and processes which were rarely applied to the pressing problems in the environment in which the students lived. (p. 318)

Hewson and Hewson (1983) also report what they consider to be a disastrous lack of success on the part of black students in science examinations in South Africa.

If the gap between students' conceptions and the scientific view is in fact wider for students in developing countries than for their Western counterparts, then clearly it would be useful to gain more information about the alternative conceptions of students in developing countries. Although there has not been a great deal of research in this area to date, it appears to be one of increasing interest. Some of the studies which have been undertaken in developing countries indicate that alternative conceptions may be strongly influenced by culture (e.g., George, 1991; Lynch & Jones, 1995; Rice, 1991; Yakubu, 1994).

George (1991) refers to these conceptions, which have their origins within the cultural context of the students, as traditional science or ethnoscience and claims that they exert a strong influence on students' learning of science. Working in Papua New Guinea, he has identified examples of traditional science which he believes are more influential in students' thinking than the Western scientific viewpoint. For example, New Guinea taxonomies of plants and animals seldom agree with scientific taxa. This is illustrated by the grouping of snakes and scorpions in a single primary taxon. Furthermore, pregnancy, according to one clan, occurs when a spirit child enters a woman and is not directly related to sexual intercourse which is viewed as playing only an indirect part in bringing a woman to general readiness for pregnancy. Frequent intercourse would, by sustained 'hammering' on the womb, assist in producing the overflow of blood which is required before any woman could be possessed by the spirit child (Shea, 1978).

A further extensive study carried out in Papua New Guinea amongst 283 student teachers revealed that 60 per cent of the students expressed qualified or unconditional belief in the power of sorcery and in malevolent spirit beings (Vlaardingerbroek, 1991).

Lynch and Jones (1995) have also studied the cultural component of students' alternative conceptions, by comparing the views of Filipino primary level students on the nature of matter, with those of Tasmanian students. They found that Filipino students from the two linguistic groups tested (Tagalog and Ilocano) had a curious and consistent interpretation of melting involving the release of water. This view was not found among the Tasmanian students, and the authors hypothesised that it probably had its origins in the 'rice/water' culture phase of the Filipino society's development, during which the addition and removal of water was so central to survival that all processes where colourless liquids were produced would be strongly associated with water. Consequently, this belief that water was released during melting, was considered to be a cultural effect. More recently Lynch (1996 a, b) claims to have identified further alternative frameworks relating to the earth, sun and moon system and the nature of matter amongst Filipino students which he also interprets as culturally determined.

Working in the Caribbean (Jamaica and Trinidad), George (1989) and George and Glasgow (1989) developed a data base which consists of 236 items of what they call 'street science.' These items consist of beliefs and sayings that deal with the same content areas that are dealt with in conventional science, but which sometimes offer different explanations to those offered in conventional science. For example, 'human hair will grow longer if it is cut when the moon is full.' The items have been collected through personal interviews with farmers, elderly citizens, medical personnel, and graduate researchers in the areas of bush medicines and Creole and oral traditions, and have been cross-referenced with high school students' alternative conceptions in an attempt to establish a source for these conceptions. The data obtained indicate that fifteen-year-olds have some commitment to street science, and George and Glasgow believe that this is likely to be a powerful source of conceptions in science for Caribbean students.

Similarly, Rice (1991) has found that Thai children are more likely to turn to cultural knowledge as the basis for understanding the causes of health and sickness rather than school knowledge. She argues that the influence of the culture in which children are brought up plays an important role in their learning process in spite of lengthy training in the classroom.

Jegede and Okebukola (1989) believe that socio-cultural interferences in science learning arise through the traditional worldview held by African students. This, they claim, is due to the conflict created when what the learner of science encounters in the school situation conflicts with the traditional beliefs passed down by the elders. However, they contend that it is not only students' content knowledge which can be affected by traditional beliefs, but also process skills such as observation (Jegede & Okebukola, 1991a). These authors found that, amongst Nigerian pre-degree science students, those with a high level of belief in African traditional cosmology made significantly fewer correct observations of biological specimens than those with a low level of belief. They concluded that high belief students probably had their achievement in observation depressed by the 'fear' of such animals as rabbits and toads brought about by traditional beliefs. The rabbit, for example, is an animal that many Africans dread because of the mystical belief that it is the incarnation of dead ancestors. Thus the sight of a rabbit in a biology laboratory could potentially scare a student who has a strong belief in the reincarnation of his/her ancestors. This situation might well result in the commitment of errors of observation.

It may be a mistake to believe that all conceptions derived from more traditional or non-technological backgrounds will necessarily impede the acceptance of the scientific view and therefore put these learners at a disadvantage compared to their Western counterparts. Work by Hewson and Hamlyn (1984) has indicated that in some cases the opposite may be true. These authors attempted to investigate whether a cultural metaphor prevalent in the Sotho group of people in southern Africa had any implications for the learning of orthodox scientific theories of heat. In the cultural metaphor the notion of 'hot blood' appeared to have connotations of agitated blood. Many subjects interviewed adhered to the heat metaphor and also tended to explain the physical phenomenon of heat in terms of ideas which the authors interpreted as 'prekinetic' or rudimentary conceptions involving moving particles that bombard each other and cause more pressure within a substance. None of the interviewees had received formal instruction in the Kinetic Theory but the notion of 'agitated blood' is not so distant from that of the energy associated with the movement of particles of a substance and the measurement of the average kinetic energy of particles (temperature). Hewson and Hamlyn came to the tentative conclusion that people belonging to the Sotho group may be at a relative advantage in learning about heat energy when compared to their Western counterparts.

> Their existing knowledge concerning heat is, in some sense, close to a kinetic view, and this could well be due to the influence of the cultural metaphor involving conceptions of heat. The research showed that most Sotho students do not have to unlearn outdated scientific notions of caloric heat (that heat is matter consisting of molecules), which are deeply rooted in Western thinking, before being able to acquire the contemporary kinetic view of heat (p. 261).

Other authors (e.g., Rollnick & Rutherford, 1993; Thijs & van den Berg, 1995; Webb, 1992), have found the alternative conceptions of non-Western students to be very similar to those reported for Western students.

In fact Thijs and van den Berg (1995) claim that in the domain of physical science the same alternative conceptions exist across many countries, with a variety of cultural and environmental contexts. In fact these authors are at odds with those who contend that non-scientific explanations that students are used to within their traditional communities could exert hindering influences on the acceptance of scientific explanations.

> In contrast to Jegede and Okebukola, we claim that the hindering effects of traditional beliefs in science are not located in the contents of such beliefs as such. We would think that in the perception of students the domains of science/physics and tradition/metaphysics do not overlap. In other words we do not believe that that there is a serious interference between the contents of traditional/superstitious beliefs and the scientific understanding, since the two domains are separated in terms of the types of questions

> considered. There is a difference between the 'how' questions which belong to the science domain, and the 'what purpose' questions on values pertaining to the metaphysical realm (p. 334).

Thus there are clearly quite differing views on the impact which traditional beliefs have on the learning of science in non-technological societies. Nevertheless, the difficulties encountered teaching science in developing countries are usually greater than those encountered in the West. Some authors (e.g., Ogawa 1986; Cobern, 1991) argue that this is because the study of science has evolved from the Western culture and, therefore, reflects Western history and Western foundation beliefs.

Ogawa (1986) (citing Ingle & Turner, 1981) believes that Western science and traditional non-Western cultures can be seen to be in conflict, as the mentality of a traditional society is dominated by myth, which provides the essential theoretical framework needed to make sense of events which do not have observable causes. This contributes to an understanding of why science education in developing countries is so difficult.

> In science education, inculcation of the scientific view of man and nature and the 'scientific' way of thinking, as if they were the only truths in the world, must result in provoking a potential antipathy against science. (p. 117)

Yakubu (1994) supports this view and states that in traditional societies, even when people have been well educated in science, if they are faced with problems, the solutions of which demand the discarding of old ideas and the consideration of new and better ones, they find it difficult to give up the old ones. Sometimes the scientific solutions are put aside and preference given to traditional or indigenous solutions. He argues that the basic difference between the two cultures appears to be the systematic experimental technique which is central to science and technology but completely absent from indigenous thought and practice. This, he goes on to state, constitutes a problem because, despite the presence of some advanced technology in the developing countries, the lives of people are still dependent on indigenous thought and practice. Yakubu justifies his views by using examples from his own research with the Mamprusi tribe in northern Ghana. From interviews with elders of this tribe it appears that the Mamprusi theoretical system consists of the 'world of common-sense observation' which includes human beings, animals, plants and inanimate objects. This is supported by an invisible world of gods, personal ancestors and good and bad spirits. Thus the Mamprusis seek to explain the world of tangible objects in terms of the invisible world.

This invisible world is not susceptible to experimentation, and Yakubu believes that without experimentation there is a 'block to falsification', progress is not feasible and traditionalism becomes the order of the day. The well-established common-sense knowledge of indigenous people has been acquired through experience and repetition so that it is second nature to them. This seems to explain why there is a tendency for even 'well educated people' to revert to the established common knowledge when scientific knowledge, which is tentative, does not give an immediate answer.

A recent wide ranging study of science teachers from five non-Western cultures (Ogunniyi, Jegede, Ogawa, Yandila, & Oladele, 1995) indicated that these teachers did not make clear demarcation between the scientific and non-scientific view. As such it was suggested by the authors that non-scientific viewpoints might influence their teaching of science. This implied that they might help reinforce or fail to correct their students' inadequate notions of science or the universe.

Given the situation discussed above, how should educators approach the teaching of science in non-technological societies? A number of authors (e.g., Ingle & Turner, 1981; Lillis, 1982; Murfin, 1994; Swift, 1992), point to the need for science curricula and teaching materials which have more relevance for learners in developing countries. Ingle and Turner (1981) decry the direct importation of Western science courses, which they refer to as 'cultural misfits', into developing countries, while Hewson (1988) believes this represents a lack of sensitivity towards the needs of the learners:

> Frequently, science courses are imported from Western countries and undergo very little modification in the process. This often leads to situations in which neither teachers nor students appreciate the point of the lessons and, as a consequence, catechetical teaching is common. (p. 318)

Swift (1983, 1987) believes that it is possible to link science to aspects of rural technology, with which students are familiar, without diluting the conceptual level of that science. Other authors, for example Macdonald and Rogan (1981) working with black South Africans and more recently Matthews and Smith (1994) with Native Americans, have demonstrated the benefits of using culturally relevant materials. In the latter case the authors found that Native American students, exposed to Native American related science materials (which included, for example, 12 biographical profiles of Native Americans who used science in their work and daily lives) had a more positive attitude and higher achievement than students who were not exposed to the culturally relevant materials. However, McKinley (1996) cautions that the incorporation of 'Indigenous knowledge', specifically 'Maori knowledge', into a science curriculum is not always straightforward, as it can be unclear what the concept of 'Indigenous knowledge' actually means.

Cobern (1996a) and Taylor (1994) are highly critical of the simple transfer of Western educational practices to other cultures. In particular, Taylor points to the dangers of the direct importation of certain Western pedagogies, such as some models of conceptual change, into developing countries. These, he believes, can undermine the integrity of the extant cultural viewpoint of members of the local culture:

> One is left, therefore, with the view that in a non-Western context, conceptual change pedagogy might serve to acculturate students into a dominant and monocultural Western scientific view that requires them to relinquish their own cultural worldviews. In a cross-cultural context there is a danger that conceptual change teaching might serve as an agent of Western cultural imperialism by devaluing the integrity of students' non-Western worldviews. (p. 7)

Ogawa (1986) argues that Western scientific views should not be presented as superior to traditional views, but rather that a comparative approach should be adopted:

> One of the main aims of science education in a non-Western society should be to compare the traditional and the scientific view of man and nature and ways of thinking, and to clarify similarities and differences between them. Once people can understand these views and ways of thinking clearly, they can make use of these understanding in their decision-making. (p. 117)

This view finds favour with Jegede (1995) who claims that instead of school science being presented as *a* way of viewing nature, children in non-Western cultures are made to accept it as *the* way, and have to replace their indigenous knowledge accordingly. This approach, he believes, has been largely responsible for the problems with learning that most African children experience with Western science in schools. As Krugly-Smolska (1996) points out, there is often an implicit assumption in science education that knowledge is not valid until the Western scientific community acknowledges it as such.

Yakubu (1994) has offered a strategy which addresses the issue of teaching science in a non-Western context while not implicitly devaluing traditional or indigenous beliefs. He argues that students in developing countries should learn about and compare the scientific and the traditional view, in such areas as medicine or farming. This strategy in which both viewpoints are valued, and there is no deliberate attempt to portray one as superior, is also advocated by Ogunniyi (1988) who suggests *harmonising* Western scientific views of the world with some of the traditional views held by those in non-Western societies. In promoting this idea of harmonisation, Ogunniyi believes that the two systems of thought are not mutually exclusive and there are ways of bringing them together. He feels it is possible to hold a scientific view as well as a traditional view of the world, perhaps in the same way in which certain scientists in the West hold the scientific and the Christian view. Thus science education must deal with conflicting views in a way that will reduce rather than increase personal confusion that might arise over specific concepts. The aim of science education, according to Ogunniyi, should not be to supplant or denigrate a traditional culture, but to help the people meet modern challenges.

Jegede and Okebukola (1991b) have employed a harmonisation style model with an experimental group of Nigerian secondary students. In a six week course on mammalian reproduction, these students were asked to state their traditional beliefs relative to the topic under consideration. After completion of the topic, students compared traditional beliefs with the information and experimentation they had undertaken. The experimental group showed significant changes in attitude and subject knowledge compared with a control group, for whom there was no comparison. This result suggested that a strategy of old view analysis followed by new view learning, combined with a process of harmonisation in which science is related directly to the indigenous culture, might contain the answer to more effective science education in non-Western societies.

This appears to be similar to a harmonisation approach developed by Rowell, Dawson and Lyndon (1990) which they refer to as *old way/new way* teaching. This has proved to be successful in the Western context, and involves comparing alternative concepts (old way) with 'scientific' concepts (new way). The old way is not necessarily rejected, and subjects may hold disparate models simultaneously.

The idea of harmonisation appears to be in accord with the views of Duit (1994), Gilbert et al. (1982), and Niedderer (1987) cited in earlier sections. Here the replacement of the students' alternative view with the scientific view was perceived to be too difficult a task. Instead, the goal was to make learners aware that there is often more than one viewpoint. This goal also finds favour with Cobern (1993b) who advocates that students talk about how what they hear from science compares to what they believe the world to be like. He believes that such frank discussion can lead to improved understanding for both the teacher and the student.

Certainly, in a non-Western context, it seems that attempting to replace traditional beliefs with the scientific view may not even be desirable let alone achievable. Indeed, Rollnick and Rutherford (1993) have concluded from their study in Swaziland that, after instruction, scientific conceptions and traditional beliefs appeared to exist side by side, in the same way as traditional medicine exists side by side with Western medicine.

This idea has recently been articulated more clearly by Jegede (1995, 1997) in a theory of collateral learning. This theory attempts to explain how non-Western learners endeavour to cope with science learning within a science classroom environment not very receptive to their indigenous knowledge. Collateral learning, he argues, represents the process whereby a learner in a non-Western classroom constructs, side by side and with minimal interference and interaction, Western and traditional meanings of a simple concept. He illustrates this with an example from

Africa about 'rainbow making.' Western science teaches that a rainbow is caused by the refraction of a beam of light by droplets of water. On the other hand traditional thought explains the appearance of the rainbow as a python, a river, or a sign indicating the passing away of an important traditional chief. Some students may not mention the latter explanation in the science classroom, but in the local community they hold the traditional explanation as a gospel truth. However, what such students have learnt about rainbows in the class remains intact to be drawn upon during an examination period if needed.

Dart (1971) has previously referred to this phenomenon whereby the Western view tends to coexist with the traditionally derived one with each exhibiting its own sphere of influence independent of the other, as conceptual dualism.

It could also be argued that the problems of learning science in non-technological societies, although they clearly exist, are overstated. In some areas of science such as sex and reproduction, Western students must be exposed to many tales which are far removed from the scientific view. These may come mainly from their peers rather than their elders, but they can nevertheless be extremely convincing to young people. A good example is provided by Carol Lee in her book *The Ostrich Position* when she mentions the case of a boy who believed his pubic hair was punishment for masturbation (Lee, 1983). Moreover, Rogers (1974) points out that such stigmas are very widespread and generally believed by children. Equally, being asked to make observations of an organism (such as a cockroach or spider) which triggers a phobic response may seriously impair this particular process skill in a Western student in much the same way as that reported previously for West African students observing a rabbit.

Furthermore, the phenomenon referred to by Yakubu (1994) of individuals reverting to traditional knowledge is not exclusive to people from developing countries, although it may be more commonplace in that context. Cobern (1993b) has observed that the study of science can have an apparent lack of influence on US students' beliefs about nature, even when the same students have been successful in tertiary level science courses.

Perhaps with the above thinking in mind, Shahn (1990a) provides a different standpoint on the cultural context of science. He argues that although contemporary science has been criticised as being culturally biased in the sense that it was developed by a predominantly white male group, reflecting European values, the validity of this criticism is questionable, as women and non-white non-Europeans have made, and continue to make, major contributions to science. Furthermore, most white males are as alienated, confused and intimidated by science as are the groups which have not fully participated in its creation, a view shared by Ogawa (1995). Simply being a white male does not by itself make a person more able to succeed in mastering or even appreciating science. As Thijs and van den Berg (1995) suggest, science seems to represent a strange world in all cultures. In fact, Aikenhead (1996) considers the typical science classroom as a cross-cultural event for many students, including the majority of Western students.

Shahn believes that technological science is steeped in an intellectual tradition, and has a formal linguistic exposition, which makes it 'foreign' to many students, regardless of their culture. He argues that culture probably plays a minimal role in limiting an individual's ability to achieve science literacy. Nevertheless, he does concede that most science instruction is built around texts which contain detailed descriptions of phenomena, and as such this may cause difficulties for members of traditional societies with a strong reliance on oral/aural interactions.

In general, Shahn believes that if taught with sufficient sensitivity, technological science should be accessible to all cultures, as the cognitive skills required to study science can themselves be learnt. He has developed a model, 'The Foundations of Science' (Shahn, 1990b), which he claims is applicable to a cross-cultural context. This model, aimed at nonscience majors, is limited to three principal themes which are considered to be milestones in the development of the modern scientific view: (a) the study of motion, of the planets and on earth; (b) the nature and properties of matter; and (c) the idea that the earth and the variety of life on Earth are the result of historical processes. Each theme is presented by following a narrative story line. This helps address the 'oral/written tradition' difficulty mentioned earlier. According to Shahn (1990a), the narrative has a historical line which starts with a consideration of phenomena accessible to untrained observers. The 'story line' adopted also shows clearly the process of concept modification and demonstrates repeatedly that the current view of the nature of science is continually changing. This view is implicitly directed at those students whose metaphysical beliefs are incompatible with science. Laboratory sessions are designed to support the story lines developed in the lectures and readings, and as the concepts become more complex and more abstract, the students are introduced to more subtle forms of reasoning and led to master the concepts. Shahn claims that this model has achieved considerable success amongst 'nonscience' students.

Bajracharya and Brouwer (1997) support the implementation of a narrative approach to science teaching. Their research with Nepalese students indicated that this approach showed considerably more promise in a society where stories are central to thinking and acting, than the lecture method of instruction normally applied.

In concluding this section, it seems that there is some difference of opinion as to the cultural status of science, and how science education might be delivered in less technological societies. Nevertheless, one common theme which emerges is the need for sensitivity towards the traditional beliefs and values held by students in these societies. It seems unlikely that this sensitivity will be achieved by the direct importation of Western resource materials, which focus heavily on Western examples, or the use of Western pedagogies of conceptual change which rely on conflict and discrepant evidence to produce cognitive disequilibrium. As stated previously, these strategies often implicitly present the Western scientific view as the only 'truth', while devaluing the students' traditional beliefs. This may ultimately develop a resentment towards science. It is particularly important that those teaching science in developing countries do not develop negative attitudes towards the subject, as there is increasing evidence (Brophy & Good, 1986; Twoli & Power, 1989) that teachers in this context can make a more substantial difference to student achievement, attitude and motivation than would be expected in developed countries.

The final part of this review will provide some background on Fiji, which is the context for this study. This will include some general information on the country, its population and education system, as well as specific information on previous research undertaken in science education.

2.9 The Fiji context

Fiji is an archipelago, comprising about three hundred islands, covering 18 300 square kilometres in the equatorial region of the Pacific Ocean. The population of approximately 757 000 (Europa Publications, 1994) comprises two major ethnic groups, the indigenous Fijians (50%) who are Melanesian and the ethnic Indians (45%) whose ancestors were brought to Fiji by the British, in the late nineteenth century as indentured labour for the colonial sugar industry. There has been little intermarriage between these two groups. The remaining five percent of the population is made up of part Europeans, Chinese, Europeans and other Pacific Islanders.

The lack of intermarriage between the two major ethnic groups, together with considerable religious and cultural differences and disparity in economic success, has resulted in a marked degree of ethnic tension. As a result, Fiji is a very racially conscious society (Tavola, 1992).

2.9.1 The education system and science education in Fiji

Prior to 1970, Fiji was a British colony, and echoes of the education system established during that period are still evident today (Taylor & Macpherson, 1993). Children begin their formal education at about age six, and follow successive stages, with science being taught at all levels, as shown in Table 2.1.

In some schools, Years 7 and 8 are the last two years of the primary system while in others they are the first two years of the secondary system. The curriculum, however, is common to both systems. All children in Fiji are offered the opportunity (although it is not a legal requirement) to receive an education up to the end of Year 10. At this point, students sit for the Fiji Junior Certificate (FJC) examination, which is the basis for selection into fifth form (Year 11). There is a further selective examination at the end of Year 12, for entry into the final year of schooling, Year 13.

In fact, education in Fiji is dominated by a series of national summative examinations. Students sit for these in Years 6, 8, 10, 12 and 13 of their schooling. Fiji is typical of the situation in many developing countries in which, according to Vulliamy (1988), the content and style of national examinations tend to be more important determinants of the content and process of teaching than syllabuses.

Table 2.1

The Structure of Schooling and Science Education in Fiji.

Primary	Secondary	Year/Grade	Science Course
Class 1		1	Elementary Science
Class 2		2	Elementary Science
Class 3		3	Elementary Science
Class 4		4	Elementary Science
Class 5		5	Elementary Science
Class 6		6	Elementary Science
Class 7	Form I	7	Basic Science
Class 8	Form II	8	Basic Science
	Form III	9	Basic Science
	Form IV	10	Basic Science
	Form V	11	Choice of Biology, Chemistry, Physics.
	Form VI	12	Choice of Biology, Chemistry, Physics.
	Form VII	13	Choice of Biology, Chemistry, Physics.

Note: In Fiji, the high school system uses the term 'Form' rather than 'Year', with the first year of high school (Year 7 of schooling) considered to be Form One.

He goes on to point out that the vast majority of questions asked in school examinations in developing countries test factual recall rather than comprehension or application skills. This encourages rote learning of factual information that is promoted by a formalistic, didactic style of teaching. Unfortunately, this places a low premium on the relevance of such teaching to the students' own lives. This point has also been made by Ingle and Turner (1981) who believe that intense pressure for university places and jobs in many developing countries puts a premium on examination success:

> In these circumstances, rote-learning appears to pay dividends, and the pupil expects the teacher to be the 'transmitter of knowledge.' Thus, even if the aims of the curriculum state otherwise, in the absence of teachers that are able to adjust to the demands of the curriculum, the new program can easily become sterile. (p. 361)

Such a situation prevails in Fiji where science examinations tend to concentrate on testing lower level cognitive skills such as recall (Taylor, 1991; Taylor & Macpherson, 1992a). This is a major contributing factor to a formalistic, teacher-centred style of science delivery, which is at odds with the aims and objectives of the science courses developed for Fiji schools (Muralidhar, 1989; Taylor & Macpherson, 1992b). Whitehead (1986) made the observation that:

> The teaching of science in many schools in Fiji is still very bookish rather than based on experiments and discovery techniques...To most people in Fiji, education is still equated with passing examinations as a means to future employment, and school committees and teachers alike are as firmly wedded as ever to examination pass rates as a measure of their success. (p. 19)

Muralidhar (1989), who observed 289 lessons of the Junior Secondary Basic Science Course, confirmed Whitehead's findings and concluded that students were rarely actively involved in what was intended to be an activity-based science program.

Other research into science education in Fiji has been limited, but a number of studies have pointed to problems of resourcing and poor maintenance of equipment as militating against good practice, particularly at the secondary level (Cook, Stir & Russell, 1992; Cook & Taylor, 1994; Mason, 1983).

Of particular significance to this study is research which indicates a marked difference in performance in science between the two main ethnic groups (Stewart, 1983; Tavola, 1992; Taylor, 1991), with Indians consistently performing better than Fijians in science examinations and tests. This is supported by data for summative examinations from the Ministry of Education (Macpherson & Taylor, 1994).

Research in other areas such as general ability (or intelligence) (Bennett, 1970; Chandra, 1975a, 1975b) and language competence (Elley & Mangubhai, 1979; Elley & Thomson, 1978; 1979) has failed to explain this apparent difference in science ability. The performance of the two ethnic groups on the Queensland Test of General

Cognitive Capacity, and various language tests (Reading, Vocabulary and Listening Comprehension) developed by the New Zealand Council for Educational Research, was not found to be significantly different. As mentioned previously, Nabobo and Teasdale (1994) suggest that the formal school system in Fiji which, in general, places a strong emphasis on rote learning may be at odds with traditional Fijian ways of learning. Greenfield (1996) whose research in Hawai'i revealed that Hawaiian (Polynesian) students demonstrated low achievement and expressed the lowest educational aspirations related to science when compared to other ethnic groups, also points to school-culture incompatibility. She suggests that while traditional classrooms tend to stress student-adult interactions, extended time commitments, and rote learning, Hawaiian culture puts greater emphasis on peer relationships and interactions, periods of hard work interspersed with periods of leisure, and on-the-job 'learning by doing'- preferably from friends.

Other workers in Fiji (Basow, 1980; Kishor, 1982) have tentatively suggested that lower levels of self-esteem amongst Fijian students as compared to Indians students may be of significance. These authors also point to the fact that Fijian students perceive a stronger external locus of control than do Indian students. To date there have been no conclusive findings to explain the difference in performance between the two groups in science, and this issue remains a major source of concern for the Fiji Ministry of Education and is one which Baba (1982) and Stewart (1983) believe is worthy of further research.

2.9.2 Primary teacher education in Fiji

Until 1982, most of the teachers for the primary sector were trained at the government-funded Nasinu Teachers' College (NTC) near the capital city, Suva. However, this was closed in December of 1982, as part of a policy to concentrate the training of primary teachers at the Lautoka Teachers' College (LTC), also government-funded and established in 1977. Two non-government institutions that run primary training programs are the Corpus Christi Teachers' College, administered by the Catholic Archdiocese of Suva, and the Fulton Missionary Teacher Training

College administered by the Seventh Day Adventist Mission. These colleges also admit students from other island nations in the South Pacific.

Lautoka Teachers' College provided the location for this research project. To gain entry to the college students are required to have passed the Fiji Form Seven Examinations taken at the end of Year 13. Typically, students enter the college at the age of eighteen or nineteen, with each cohort containing approximately equal numbers of males and females from both indigenous Fijian and ethnic Indian populations. This is a result of a quota policy aimed at ensuring gender and racial equity. The students undertake a two-year training program, covering the content of the subjects they will be expected to teach in the primary curriculum, along with a series of general education courses. The program also involves seven weeks of teaching practice.

The science department offers four courses, of which three, Curriculum Studies in Science (CSS) I and II and School Gardening, are compulsory, while the fourth, Environmental Science is an elective. Curriculum Studies in Science I, undertaken in the students' first year at the college, is designed to introduce the students to the objectives and content of the Elementary Science course, taught in Fiji primary schools from Years 1-6. Curriculum Studies in Science II, a second year course, is more advanced, as it introduces the students to the Basic Science course, taught in those primary schools which have a Year 7 and 8.

Because of the somewhat anomalous overlap between the primary and secondary systems in Fiji (see Table 2.1), the Basic Science course is also taught in Forms 1 and 2 of some high schools. In the high schools this teaching is usually undertaken by a science subject specialist, but this is not the case in those primary schools which cater for Years 7 and 8. Such schools represent the majority situation, some 80% of the country's primary schools. Thus, many primary teachers, who are not subject specialists, must be prepared to teach topics such as Pressure, Light, Sound, Nutrition, Density and Matter. Given the abundant evidence of the difficulties primary teachers in other countries encounter with some of these topics, it seems likely that they will prove conceptually difficult for non-science specialists in Fiji. Certainly, Muralidhar (1989) provides evidence of the difficulties, both conceptual and practical, which he observed student-teachers, who were subject specialists, experiencing with science:

> Working with student-teachers, I began to realise that they had great difficulty in explaining basic concepts in their subject area and in planning simple demonstration experiments. Students who were majoring in physics confused a lens with a mirror, and an electric motor with a dynamo. They could, without much difficulty, state Newton's laws of motion but struggled to apply them in simple situations. (p. 43)

One might anticipate this situation being more extreme amongst the non-specialists teaching primary science.

At LTC, the students receive a total of three hours per week of science instruction in the form of lectures, seminars, group work and laboratory practical sessions. This is intended not only to make them conversant with the content matter of the school science courses, but also to equip them with pedagogies appropriate for conducting inquiry-orientated lessons. During these sessions they are also instructed in designing science activities, constructing test items, and improvising teaching aids.

2.10 Directions from the literature survey

A considerable body of evidence has been provided in the review of literature indicating that primary teachers in many countries (both developed and developing) hold alternative conceptions in a range of science topics. This lack of understanding of the scientific view appears to have a serious impact on teacher confidence and teaching style in science. Although a search of the literature indicates that little research into alternative conceptions has been undertaken in Fiji, my own experience of running in-service science courses with primary teachers there suggests that alternative conceptions are prevalent. The style of teaching science in Fiji is very formalistic, and although the 'examination culture' contributes significantly to this, teachers have also expressed considerable anxiety about their own lack of scientific knowledge, which I would suggest contributes to this style of teaching as well. Muralidhar (1989) supports this view when he states that because of their inadequate background in science, most primary and middle school teachers adhere rigidly to the Teachers' Books and present lessons with very little variation. Few teachers he observed moved beyond the book and developed creative approaches suitable for their students. In the more extreme cases Muralidhar noted that teachers omitted activities with which they were not confident.

> Teachers' lack of confidence in handling certain activities sometimes resulted in their skipping an activity entirely or abandoning the activity halfway; students were simply asked to copy the expected results into their books. (p.281)

Much of this behaviour appeared to Muralidhar to result from a poor understanding of physical science.

> Students' work in science was also affected by the confidence teachers had in managing activities. Many teachers felt uncomfortable when it came to Basic Science activities...that related to physics or chemistry. My observations indicated that some teachers were having difficulty coping with units like 'Weather', 'Metals', 'Machines', 'Ships and the Sea' and 'Sources of Energy' (p. 279).

Further evidence for this came from interviews with individual teachers. One teacher made the following comment:

> I don't like teaching Form 2 (Year 8) Basic Science - too much physics in it and I haven't done physics (at school) - the only physics I picked up was at USP - managed to get C. So, I feel if you know the background in detail, then it is easier to get things through than going back to books and reading them and getting it to the students. (p. 281)

This was one of a number of examples cited by Muralidhar (1989). In all cases the teachers quoted had attended university, where they had completed some science courses. The situation is likely to be more difficult for those primary level teachers taking Year 7 and 8 classes with considerably less background in science.

This problem is compounded in Fiji, where for cultural reasons it is important that teachers maintain tight control over their classes and do not 'lose face' by admitting to a lack of knowledge. Thus discussion or questioning on the part of students is frequently discouraged, particularly by those teachers uncertain of their own scientific knowledge. These teachers fear their lack of understanding being exposed before the class, and adopt strategies which will minimise this risk.

A similar situation has been reported in Papua New Guinea (P.N.G.), another Melanesian country in the South Pacific region (Waldrip & Giddings, 1993):

> In Papua New Guinea society, the elders are the source of knowledge and often younger members are perceived to be full of foolish ideas. Directions emanate from the elders and so in teaching, the teacher likewise directs the class. (p. 12)

Confirming this view, Apelis (1980) states that P.N.G. teachers like to impose a teacher-centred classroom in order to keep control of the system. However, Waldrip and Giddings went on to point out that science teachers in that country appeared to be receptive to new ideas as, during school visits, teachers privately requested impromptu lesson demonstrations. These authors were encouraged that the teachers appeared to appreciate observing new methods that they could then start to imitate.

The Basic Science course, which many primary teachers have to teach, is largely a Western style model with some local examples provided to give it greater relevance to the students. While this course may not be ideal for the Fiji context (Muralidhar, 1989) it is unlikely to change much in the near future because of the slow pace of curriculum development in that country. In the meantime, it is important that those who must teach the course have a proper understanding of the scientific concepts involved for, as Novak (1990) suggests, if prospective teachers are to adopt practices that encourage meaningful learning, it seems evident that they must also seek to learn subject matter meaningfully.

Given the complexities of the Fiji situation and in particular the disparity in performance in science of the two major ethnic groups, this presents those involved in teacher education with a considerable challenge.

The final section of the literature review suggested a number of questions of interest to this researcher:

1. What alternative conceptions do Fiji pre-service primary teachers hold about changes in matter and the application of Kinetic Theory to this?

2. How prevalent are these alternative conceptions within the two major ethnic groups (Indian and Fijian) which make up this target population?

3. Can a teaching approach based upon a constructivist view of learning effect improved conceptual understanding of this aspect of science within the target population?

4. Will such an approach prove to be appropriate for use with both ethnic groups?

In the chapter which follows, the strategy which was used in an attempt to answer these questions will be outlined in detail.

Chapter 3

Methodology

3.1 Introduction

At the conclusion of the previous chapter a number of questions were raised concerning the training of Fiji pre-service primary school teachers in science. These were:

1. *What alternative conceptions do Fiji pre-service primary teachers hold about changes in matter and the application of Kinetic Theory to this?*

2. *How prevalent are these alternative conceptions within the two major ethnic groups (Indian and Fijian) which make up this target population?*

3. *Can a teaching approach based upon a constructivist view of learning effect improved conceptual understanding of this aspect of science within the target population?*

4. *Will such an approach prove to be appropriate for use with both ethnic groups?*

In this chapter I outline the theoretical position which frames these questions and the methodology used to address them. I then go on to describe the specific research methods utilised within this methodology.

3.2 Theoretical considerations

The study was conceptualised within a constructivist epistemology. This researcher holds a constructivist view in seeing students as being purposive, and therefore constructing knowledge through social interaction and their interactions with the physical environment. Or as stated by Tobin, Butler Kahle and Fraser (1990):

> Within a constructivist framework learning is defined as the construction of knowledge by individuals as sensory data are given meaning in terms of prior knowledge. Learning is an interpretative process, involving constructions of individuals and social collaboration. (p. 411)

Thus, the central premise of the constructivist epistemology is that knowledge, whether public or private, is a human construction. A key feature of this perspective is that human beings construct mental models of their environment and new experiences are interpreted and understood in relation to existing mental models and schemes (Driver, 1988).

Millar (1989) has pointed to the valuable contribution this view has made to thinking in science education:

> The constructivist approach offers an insight that is enormously valuable, in emphasising that *any* knowledge is necessarily reconstructed by the learner in the learning process. We cannot teach a body of knowledge by direct transmission; the learner is always involved in reconstructing the meaning personally. (p. 592)

Although constructivist epistemology is not universally accepted (e.g., Matthews, 1993), Duit (1994) argues that it has been a most powerful and fruitful driving force in research on students' and teachers' conceptions, while Summers (1992) contends that it is now widely valued as a theoretical basis for developing learners' ideas in science. As has been demonstrated in chapter 2, constructivist thinking is now influencing science educators' views on curriculum development and teaching and learning in the science classroom (Driver, 1989), and this influence has extended to the training of primary level teachers in science in the United Kingdom (Summers & Kruger, 1994).

However, in many developing countries it appears that constructivist inspired strategies are rarely implemented in the teaching of science at any level. While it could be argued that this is also the case in many Western classrooms (e.g., Tobin & Gallagher, 1987), the evidence from chapter 2 would indicate that the situation is much more extreme in developing countries. Muralidhar (1989) found this to be true in Fiji from his extensive observations of classroom practice:

> Most teachers did not realise the potential of questioning and discussion, and as a consequence missed out on understanding the ideas their students had about important concepts. (p.270)

Often a transmissive approach to science teaching predominates, with teacher exposition being the major method used in the delivery of the curriculum. Ingle and Turner (1981) argue that this approach has been singularly unsuccessful in encouraging students in developing countries to think 'scientifically':

> Straightforward 'teaching by telling', with an emphasis on rote learning, cannot be an effective method of achieving this end, as the facts and ideas are simply absorbed without any process of internalisation. Some sort of more active method, requiring the pupils to experiment and discuss, to observe and interpret at their level, is likely to be more fruitful. (p. 366)

Thus it appears that, in terms of producing students who have a sound conceptual understanding of science which they can apply to novel situations, the system is failing in many of these countries (Hewson, 1988; Elkana, 1981). In fact Lewin (1993) has observed that, in some developing countries, basic science was being retaught at the tertiary level at a much higher cost to make up for the shortcomings of science education in the school system. This is certainly true in Fiji, where a great many students arrive at the University of the South Pacific unable to cope with science at this level (Taylor, 1993).

Thus the transmissive approach to science teaching, so extreme and pervasive in Fiji schools, is apparently not working. It would, of course, be naive to claim that this is the sole causative factor for the shortcomings of the system, but it is likely to be an important one. There is also emerging evidence that students in developing countries hold many alternative conceptions which can affect their learning of science in similar ways to their Western counterparts (e.g., George, 1991; Lynch & Jones, 1995). If such a situation also prevails in Fiji, then clearly a transmissive approach to teaching, which takes no account of these alternative conceptions, is unlikely to achieve learning with understanding.

As Fiji develops economically and becomes more industrialised, there is a growing demand for individuals with science backgrounds, who have the ability to analyse and put forward strategies for solving problems. This is particularly true in the area of environmental management, as the rapid pace of development now threatens the fragile ecosystem of the islands. Such a need is unlikely to be readily met by students who have been exposed to a largely transmissive form of science instruction. Thus there is a strong argument for attempting to improve the teaching of science in Fiji at all levels. While achieving a significant improvement is a difficult and complex task, one possible starting point would be to provide primary teachers with a sound understanding of the scientific concepts they are required to teach. Although this, in itself, does not guarantee better teaching practice, it would appear to be a necessary prerequisite. Certainly, without such an understanding, primary teachers are unlikely to encourage their own students to ask questions and engage in discussion and other activities about concepts which they themselves do not fully comprehend.

It is interesting to note that a former Chief of Mission of UNESCO for the South Pacific Region recently made reference to primary level science education. Speaking to a meeting of the regional Directors of Education Mr. Fred Griffiths made the point that there was a problem with the quality of primary science education throughout the region:

> If we do not have good quality primary (science) education, we cannot expect secondary education to do remedial work and pick up the slack, so the idea is to build quality primary education which will lead to a better secondary education, which will lead to more capable people to take up the thrust of national development at the end of the scale. (Griffiths: cited in the University of the South Pacific Bulletin, 1995)

As it has been suggested that a transmissive training model is unlikely to provide primary teachers with sufficient understanding of science to achieve this goal, this researcher would argue that a constructivist approach, which takes into account learners' prior conceptions and ways of thinking, may prove to be more effective.

Although there have been comparatively few studies on the impact of a constructivist teaching model in developing countries, those undertaken to date have shown some promise in developing a better conceptual understanding of science than more traditional approaches (e.g., Hewson & Hewson, 1983; Jegede & Okebukola, 1991b; Rollnick & Rutherford, 1993). This exploratory study adds to the limited body of information available for developing countries by providing data on the effectiveness of a constructivist model of teaching and learning in Fiji.

The existing transmissive approach to science education in Fiji appears, in general, to be more successful with the ethnic Indians, than with the indigenous Fijians. Having said this, most of the learning in science throughout Fiji seems to be strictly by rote, resulting in limited understanding of the underlying concepts (Muralidhar, 1989). Thus it was of interest to see if a constructivist model which involved elicitation and discussion of prior conceptions along with other strategies such as the use of analogy, collaborative group learning in which small groups of students jointly worked out solutions to various problems and concept mapping, would prove to be more effective in providing both cultural groups with a deeper understanding of important scientific concepts.

In proposing this approach, the researcher was influenced, in particular, by both the contextual and social constructivist perspectives (Cobern, 1993a; Solomon, 1987 respectively), which were discussed in chapter 2. Clearly, in dealing with students from different cultural backgrounds, it was important, as suggested by Cobern, to establish if their prior conceptions, in a specific domain of science, originate from or are influenced by a shared world view held by their particular culture. This required close comparisons of the prior conceptions held by both Indians and Fijians and where consistent differences occurred, further probing in an attempt to determine if they derive from differing world views.

Furthermore, the nature of Pacific Island cultures, with their strong oral traditions and emphasis on co-operativeness might indicate that pedagogies derived from the social constructivist perspective, which stress the sharing and co-construction of knowledge could be appropriate in this context. Certainly, Solomon (1987) claims that the social scene makes an essential difference to the learning situation, and suggests further that social constructions of meaning within practical groups may prove to be more important than the experimental results or even the mental constructs of individuals. Other theorists such as Vygotsky (1987) also advocate taking advantage of the social nature of learning to foster knowledge construction. Vygotsky has argued that the social context of learning may be used to extend what he referred to as the 'zone of proximal development,' such that learners can be more effective than if they were learning alone. The role of the social context is to scaffold the learner, making it possible for him/her to progress further than would be possible without this support.

Thus providing Fiji students with simple scientific problems to be discussed in groups may be appropriate to their cultural context. Clearly it would offer a strong contrast to the didactic practices which dominate many of the science classrooms in Fiji where it is not uncommon to hear the term 'cramming' used by students and teachers alike.

As mentioned previously, the strategies referred to above have been developed and researched in the West, and little is known about their appropriateness in other cultural settings. Thus the study attempts to determine not only whether a constructivist approach to learning could effect improved conceptual understanding of physical science in pre-service primary teachers in Fiji, but to document the reactions of teachers from both cultural groups to the novel techniques. In so doing, the study provides information as to which particular strategies student teachers found most effective in changing their conceptions.

3.3 Methodology

Before embarking on a description of the methodology it is important to clarify some of the terminology to be used, particularly as there is often a lack of consistency, and apparently some confusion, over the use of the terms 'methodology' and 'methods' in the literature. According to Burgess (1984) 'research methodology' involves a consideration of research design, data collection, data analysis and theorising, together with the social, ethical and political concerns of the social researcher. It is in this broad sense that the term methodology will be used below. This is distinct from the 'research methods', which represent only a part of the overall methodology and which, in this study, will refer specifically to the strategies and instruments to be used for data collection within the methodology. As such the methods for data collection are encompassed within the broader methodology.

The history of methodology in educational research since the turn of the century has been dominated by a quantitative orientation (Rossman & Wilson, 1985).

Educational research, and indeed research in other social sciences, has generally followed the traditional positivistic scientific methodology. Since the 1960s, however, a strong move towards a more qualitative or interpretative approach has left educational research divided between two competing methodologies: the scientific empirical tradition, which generates data to which the power of mathematical analysis can be applied and which attempts to establish general laws or principles, and the naturalistic phenomenological approach to research, which emphasises the importance of subjective experience of individuals (Burns, 1994).

According to Burns, both these methodologies have their strengths and limitations. The main strengths of quantitative methodology lie in its precision, control and generalisability. Control is achieved through sampling and design; precision through quantifiable and reliable measurement. A further strength is that experimentation leads to inferences about causation, since the systematic manipulation of a variable can be inferred to have a direct causal effect on another, assuming other variables have been controlled or eliminated. However, many researchers are concerned that the scientific quantitative approach fails to make adequate allowance for human individuality, as this type of research leads to the assumption that facts are true and the same for all people all the time.

Qualitative research methodologies, on the other hand, tend to be based upon a recognition of the importance of the subjective, experiential 'life-world' of human beings. Their main strength is that they can play an important role in suggesting possible relationships, causes, effects and even dynamic processes in school or other learning settings. The data obtained can also highlight subtleties in learners' behaviour, illuminate reasons for action and provide in-depth information on teacher interpretations and teaching style (Burns, 1994).

Nevertheless, qualitative forms of research are often criticised due to problems of adequate validity, reliability and generalisability. Because of the subjective nature of qualitative data, it is difficult to apply conventional standards of reliability and validity. As Miles and Huberman (1984) argue, although qualitative data are a source of well grounded, rich description and explanation of processes occurring in local contexts, the researcher needs to be confident that the conclusions are not unreasonable, and that another researcher facing the data would reach similar conclusions.

Because these two methodologies appear to derive from opposing theoretical and philosophical perspectives, that is, quantitative being grounded in a positivist or realist paradigm and qualitative deriving from an interpretative or relativist paradigm, many researchers have taken the stance that their trade is a single-methodological enterprise. According to Rossman and Wilson (1985), purists usually focus at the paradigm level and maintain that the methodologies encompass different assumptions and are therefore not compatible within the same study. Certainly, Smith (1983) argues that the two approaches cannot be combined, and Burrell and Morgan (1979) assert that different paradigms are mutually exclusive.

This view that the positivist and interpretative perspectives on research are apparently incompatible, and should not be combined in a single study, has been attacked by a number of authors (e.g., Goodwin & Goodwin, 1984; Mason, 1993; Reichardt & Cook, 1979). They claim that the paradigm argument is fairly irrelevant and strongly advocate the combined use of the two approaches, while Niaz (1997) asserts that advocates of the qualitative paradigm are largely inspired by a single philosophical standpoint, that of Kuhnian incommensurability. Niaz argues that this is a major obstacle to integration and calls a broader philosophical view in order to encourage the integration of qualitative and quantitative research methodologies in science education. Increasingly, researchers are ignoring tradition and combining quantitative and qualitative research methods within the methodology for a single study, as they find that the accepted narrow pathways defined by the paradigm argument do not suffice, and that a combined methodology is most appropriate to answer the research questions that are posed (Mason, 1993). In fact Cizek (1995) suggests there must be a renewed awareness that qualitative and quantitative methodologists are often investigating the same things, or at least different facets of the phenomena of interest.

Goodwin and Goodwin (1984) claim it is a 'myth' that qualitative and quantitative research strategies represent clearly different, and mutually exclusive paradigmatic perspectives. They assert that the qualitative-quantitative distinction is one of methods of data collection, analysis and interpretation, and that it is possible to approach the study of a phenomenon with a certain paradigmatic orientation using either methodology:

> Although certain methods are usually linked to certain paradigms, the association between paradigm and method is far from exclusive. The choice of research procedures-including design, sampling plan, instrumentation, data collection methods, and data analysis techniques-should match the research question and be optimally efficient, powerful, valid and reliable. Sometimes the methods of choice will be qualitative, sometimes quantitative, and sometimes they will be a combination of both procedures. Trying rigidly to link paradigm and method will inevitably lead to research that is conducted inappropriately and which, therefore will produce findings that lack credibility. (p. 378)

Miles and Huberman (1984) also regard methodological pluralism as being the pragmatic approach to take if educational research is to advance and more recently Tobin et al. (1990) have advocated the combined use of qualitative and quantitative methods of data collection in learning environment studies, claiming that a triangulation using data from both sources enabled greater confidence to be placed in their findings and richer insights into classroom life to be gained.

A number of other authors have justified this position further. Rossman and Wilson (1985) argue that typically qualitative methods can be used to enrich the bare bones of statistical results, while Goodwin and Goodwin (1984) contend that many studies can be enhanced if a combined approach is undertaken.

> It is sometimes advantageous to add a qualitative component to what is basically a quantitative design to increase the meaning of the obtained data. For example, qualitative measurement techniques such as intensive observation or interviews can help the researcher identify the values and perspectives of subjects in ways that are often impossible with strictly quantitative strategies. (p. 380)

Perhaps Filstead (1979) best summarised this situation when he wrote:

> Perhaps the bottom line in the integration of qualitative methods with quantitative methods is that the qualitative methods provide the context of meaning in which the quantitative findings can be understood.(p. 45)

Certainly Miles and Huberman (1984) maintain that an increasing number of 'quantitative' methodologists, operating from the logical positivist stance, are using qualitative, naturalistic and phenomenological approaches to complement tests and surveys.

However, Shotland and Mark (1987), while advocating the integration of qualitative and quantitative data collection methods in certain circumstances, caution that such an approach is not without its problems. They argue that great care is required when drawing inferences from studies employing multiple or mixed data collection methods in a single study. Researchers, they believe, often fall into the trap of employing data collection methods which are biased in the same direction, or alternately using different methods which are examining different questions. They call for the systematic use of multiple or mixed methodology designs, as their uncritical use is likely to lead to greater confusion than clarification.

To this end Greene, Caracelli and Graham (1989) developed a conceptual framework which they believe allows for a more thoughtful and defensible use of the multiple or mixed methodology enquiry. They defined their understanding of mixed method designs as those that include at least one quantitative method (designed to collect numbers) and one qualitative method (designed to collect words), where neither type of method is inherently linked to any particular inquiry paradigm. While this 'definition' seems somewhat simplistic given that qualitative methods can generate data that are presented numerically and manipulated statistically, it has allowed the development of a very useful conceptual framework for workers who wish to employ mixed method designs in their research.

As part of this framework, the authors have identified five different purposes for using a mixed method design. These are summarised below:

1. *Triangulation* - seeks convergence, corroboration, correspondence of results from the different methods.

2. *Complementarity* - seeks elaboration, enhancement, illustration, clarification of results from one method with the results from the other method.

3. *Development* - seeks to use the results from one method to help develop or inform the other method, where development is broadly construed to include sampling and implementation, as well as measurement decisions.

4. *Initiation* - seeks the discovery of paradox and contradiction, new perspectives of frameworks, the recasting of questions or results from one method with questions or results from the other method.

5. *Expansion* - seeks to extend the breadth and range of enquiry by using different inquiry components.

This work provides a helpful framework for clarifying the design options for mixed method approaches to research.

Vulliamy (1990) has written specifically about educational research in developing countries. He comments that quantitative research still remains the tradition in such countries, with few widely known examples of qualitative research studies. Discussion of educational innovations in developing countries has tended to be conducted at the level of policies, plans and rhetoric, rather than considering the practice of such policies in the schools or colleges themselves. This, Vulliamy believes, reflects two factors. Firstly, prior developments in qualitative research strategies and in qualitative educational evaluation have not yet generally been incorporated into educational research environments in developing countries. Secondly, international organisations such as the World Bank, which have been playing a more prominent role in funding and evaluating educational innovations in developing countries, were firmly wedded to traditional quantitative designs.

Shaeffer (1986) agrees, having noted that:

> In much of the developing world, educational research is largely empirical and quantitative, characterised by the development of standardised tests and

> questionnaires, the production of data from large samples of schools and individuals, and the analysis of these data by a variety of statistical methods. (p. 5)

One consequence of this, according to Vulliamy (1990), is that there have been some educational research questions in developing countries to which a quantitative research strategy has been applied when either a qualitative one or a combination of the two would have been more appropriate. In addition he believes some research questions have rarely been addressed at all despite their potential relevance to both the process of policy making and to the more theoretical study of schooling in the developing world.

Vulliamy believes there is a need to broaden the use of educational strategies to include a full range of quantitative and qualitative strategies in developing countries. By way of justification he suggests that, by providing analyses which are strongly related to the cultural context of schooling, qualitative research can also play a useful role in identifying the most appropriate questions to address in large-scale quantitative research studies. Furthermore, he argues that qualitative research techniques are especially suited to the early stages of the implementation of an innovation, whilst more quantitative measures of outcomes may be required to assess the impact of an innovation, once it has been effectively implemented.

Lewin (1990b), writing about the design of research projects he had undertaken in developing countries, specifically Malaysia and Sri Lanka, argues that in this context as in the West, educational research should not be limited exclusively to a single research paradigm, nor to a single set of data collection methods located within one paradigm. He, like Goodwin and Goodwin (1984), believes strongly that the researcher has to make choices, predominantly on the basis of research questions, and therefore must select approaches and methods most likely to provide insight and explanation into matters of concern.

> Though epistemological assumptions underlying approaches do differ, this does not seem to me to lead to the conclusion that a research study is bound to a single set of these for all its data collection and analysis. Rather the researcher should exploit those data collection and analysis techniques which offer most promise of useful insights, and recognise the epistemological assumptions which may accompany them (p. 47).

This researcher holds with the pragmatic views on research methodology espoused by such writers as Goodwin and Goodwin (1984), and Lewin (1990b), in believing that the choice of data collection techniques should be made on the basis of research questions, and need not necessarily be limited to a single research paradigm. Thus in addressing the four research questions outlined in the introduction to this chapter, the methodology employed involved a number of different qualitative and quantitative methods. For example, a qualitative approach involving in-depth interviews was adopted to address the first of the research questions, while a quantitative survey instrument was used to help answer the second question. It was the view of the researcher that these data collection methods, located within different research traditions, were the most appropriate and offered the most promise for addressing the aforementioned questions. Henceforth the methodology of this study will be referred to as a mixed methodology.

A number of prominent science education researchers (e.g., Tobin et al. 1990) are now combining quantitative and qualitative data collection methods to enhance their research, while others concerned specifically with improving primary teachers' understanding of science have also employed a mixed methodology in their research projects. As referred to in chapter 2, Kruger, Palacio and Summers (1990; 1992) working with primary teachers in the UK, and Rollnick and Rutherford (1990) conducting similar research in Swaziland, have used a combination of qualitative and quantitative methods to answer specific research questions within a larger study.

The mixed methodology design employed in this project also addresses the concerns expressed by Vulliamy (1990) who called for a broadening of research strategies in developing countries. In particular, as he recommended, it drew on qualitative findings to inform later quantitative stages of the research study.

The various qualitative and quantitative data collection methods which make up this study were utilised within a development design as outlined by Greene et al. (1989) in their conceptual framework for mixed methodology research. The salient feature of such a design is the sequential timing of the implementation of the different methods. One method of data collection is implemented first, and the results are used to help select the sample, develop the instrument, or inform the analysis for the other method. Thus, implementation is both sequential and interactive. The section which follows outlines, in detail, the research design and data collection methods used in this study.

3.4 Research design and data collection methods

As mentioned above, the proposed research methodology employed a combination of qualitative and quantitative methods with the results from each method being used to inform later methods (Greene et al. 1989). A preliminary pilot study, which was conducted in Australia, will be described in chapter 4. The main study was undertaken in Fiji at the Lautoka Teachers' College, and comprised four phases:

1. *An Elicitation Phase*
2. *A Prevalence Phase*
3. *An Experimental Phase*
4. *An Evaluation Phase*

Each phase of the design addressed one of the four questions outlined in the introduction to this chapter. The phases are discussed in more detail below.

3.4.1 The elicitation phase

This phase of the research design addressed the first question outlined in the introduction, namely: *What alternative conceptions do Fiji pre-service primary teachers hold about changes in matter and the application of Kinetic Theory to this?*

The aim of this qualitative phase was to probe the conceptual understanding of a representative group of pre-service primary teachers in the area of Kinetic Theory and its application to changes in matter. This was intended to reveal the alternative conceptions, in this particular domain of science, held by each ethnic group, and to determine to what extent particular individuals had difficulty conceptualising a molecular model of matter.

3.4.1.1 Data collection methods for the elicitation phase

A number of research methods can be used to probe subjects' understanding and prior knowledge of particular aspects of science. These have been reviewed by, amongst others, Stewart (1980), Sutton (1980), and White and Gunstone (1992). In summary, for the purposes of identifying and exploring alternative conceptions with a small number of subjects, interviews appear to offer the researcher greater flexibility than other possible methods such as word association, concept mapping or written responses to set questions. This is primarily because an interview allows the researcher to ask for further clarification of specific points of interest, and thus probe more deeply into the subject's understanding of certain phenomena.

In the interview situation the researcher attempts to combine two almost incompatible features - letting the subject talk freely, while probing to check the basis of his or her reasoning. Typically interviews start with open-ended questions, and acceptance of answers following the subject's reasoning wherever it leads. Later the researcher may probe more specifically to encourage elaboration of earlier answers, and to get the subject to give reasons for his or her inferences, or make predictions (Sutton, 1980). As mentioned previously, this method is highly flexible, allowing a skilful researcher both to probe the areas of the knowledge domain of particular interest and to let the subject talk freely, while constantly checking his or her spontaneous remarks for those that will prove genuinely revealing (Posner & Gertzog, 1982).

A number of adaptations of the clinical interview have been developed for probing conceptual understanding in science. Three of these: 'interviews-about-instances'; 'interviews-about-events'; and 'prediction-observation-explanation' were the methods of choice for the initial phase of this project. They are discussed in more detail below, along with a justification of their use in this phase of the research.

Interviews-about-Instances (IAI) and Interviews-about-Events (IAE)

An interview about an instance is a probe of a subject's understanding of a single concept. It checks not only whether the subject can recognise if the concept is represented in specific instances, but also whether the subject can explain his or her decision. This technique has been developed and extensively used by Osborne and Gilbert (Osborne & Gilbert, 1979, 1980a, 1980b). These authors based their idea for this technique on the views of Klausmeier, Ghatala, and Frayer (1974) and Markle and Tiemann (1970) who suggest that concept attainment is closely related to the ability of an individual to categorise instances not previously encountered, as instances or non-instances of a particular concept.

In order to explore a subject's understanding of a particular concept, using this technique, up to 20 familiar situations are presented to the subject, each depicted on a separate card, usually by means of a line drawing (see Figure 3.1).

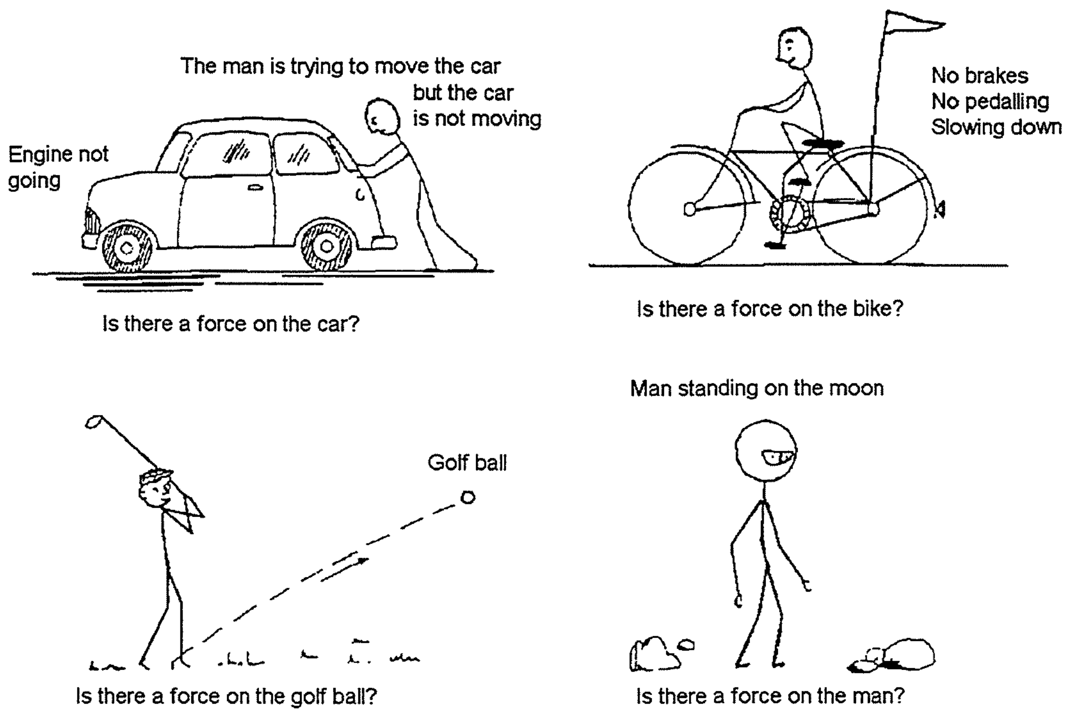


Figure 3.1. Four examples of interview-about-instances cards on the concept of force. (Osborne & Gilbert, 1980b)

The cards normally include situations which contain an instance of the concept and situations which do not contain instances of the concept. Subjects are asked, for each situation in turn, whether they consider it contains an instance of the concept or not. The subject's reason for his or her choice in each case is then elicited. The explanation reveals not only the quality of the subject's understanding, but also alternative conceptions, where they exist (Osborne & Gilbert, 1980b).

Interviews about events are similarly effective probes of understanding, though the target now is not the ability of the subject to recognise the presence of a concept, but ability to explain a phenomenon. The distinction between instances and events is blurred, as the cards that are used in interviews-about-instances often represent events. According to White and Gunstone (1992), the distinction is not particularly important, because interviews-about-events will reveal the subject's understanding of associated concepts. However, there is some difference in procedure, because in interviews-about-events the focusing question is not limited to asking whether the drawing illustrates an instance of the target concept. The range of questions can therefore be broader.

Typically, the interviews are audio-taped or videotaped and later transcribed for analysis.

These techniques offer a number of advantages, as summarised by Osborne and Gilbert, (1980b).

1. They are applicable over a wide age range;
2. They are generally enjoyable for interviewer and interviewee;
3. They have the advantage over written answers in terms of flexibility and depth of investigation;
4. Classifying instances is more penetrating than asking for definitions;
5. They are concerned with the subject's view rather than merely examining if the subject has the correct scientific view.

However, there also some limitations and difficulties (Osborne & Gilbert, 1979):

1. There are problems of choosing a limited but adequate set of instances or events so that various aspects of a subject's concept will be exposed;

2. Choosing a suitable order for the presentation of instances, bearing in mind Gilbert, Watts and Osborne (1985) suggest that for IAI, the initial examples should be instances of the concept followed by a sequence of non-instances, with a final sequence of more difficult examples;

3. Interviews, and the transcribing and analysis of transcripts, are time consuming:

4. There are the difficulties associated with interviews and the analysis of the interview data, e.g., difficult to report succinctly.

Nevertheless, the insights gained justify the time commitment, while experience overcomes the difficulties pertaining to interviewing. Certainly it is the flexibility of being able to have subjects clarify their responses or reiterate certain important points which makes these instruments particularly suitable for the initial phase of this research project.

Although these methods for probing understanding were developed some time ago, according to Treagust (1988) they are the methods of choice for most of the research in this area. Certainly they have been used in a large number of studies on alternative conceptions over a considerable time span (e.g., Mitchell & Gunstone, 1984; Primary School Teachers and Science Project, 1993). Furthermore, although many of these studies have been conducted with high school level students, the techniques have recently been used extensively and effectively with primary school teachers in the UK (Summers & Kruger, 1994). They have also been employed in a number of non-Western settings, for example, by Hewson (1982) with African students and Rice (1991) with Thai students. This wide range of usage over time and context point to the versatility and enduring effectiveness of the IAI and IAE techniques. Certainly, White and Gunstone (1992) maintain that they continue to be amongst the most effective probes of students' understanding of single concepts and various phenomena.

In conducting the interviews the researcher was informed by the guidelines for employing this technique provided by Bell and Osborne (1981) and Gilbert, Watts and Osborne (1985). During his four years working in Fiji, the researcher had conducted a considerable number of interviews with students and teachers as part of various research projects (e.g., Cook & Taylor, 1994; Taylor & Macpherson, 1993). Prior experience of interviewing subjects from different cultures was particularly valuable when executing this phase of the research.

Prediction-Observation-Explanation (POE)

Prediction-Observation-Explanation requires subjects to carry out three tasks. First they must predict the outcome of some event, and must justify their prediction; then they describe what they see happen, and finally they must reconcile any conflict between prediction and observation (White & Gunstone, 1992). As a prediction is likely to require genuine application of knowledge, the POE method should prove effective in probing subjects' ability to apply Kinetic Theory to other aspects of science. Thus the use of POE complemented the other two methods (IAI and IAE), and added some variety to the interview experience for the subjects. Although this procedure lends itself to a written response, the pilot study described later revealed that such responses are often limited or unclear, so for the purposes of this research the procedure was conducted in the form of an interview. This allowed for the clarification and expansion of specific points of interest.

A modified version of this technique has been used by Rollnick (1988), to probe African primary teachers' understanding of pressure. In this case small groups of teachers either observed the performance of experimental tasks or, if they wished, conducted the tasks themselves. They were then asked to explain what they had observed and could talk freely and explore their ideas before providing an explanation. The discussions and explanations were audio-taped, and the procedure proved to be very effective in eliciting the teachers' scientific and alternative conceptions about the phenomena observed.

Implementation of the elicitation phase

A pilot study was undertaken in Australia in order to refine the interviewing procedure to be used in this first phase of the data collection. The pilot study is described in detail in the following chapter, which contains information not included here to prevent repetition.

Because of the questions posed at the outset of the study and the heterogeneity of the population at the college, it was important that individuals from all the different sub-groups were represented within the overall group of subjects interviewed. Thus the subjects, who were all volunteers, were selected to be representative of Fijians and Indians; males and females; those from urban and rural backgrounds and individuals with differing backgrounds in science (see Table 3.1).

A total of 24 individual interviews, involving IAI, IAE and POE techniques, were conducted with these students in the first phase of the research. By the completion of the final interview, no additional alternative conceptions were appearing and it was considered that sufficient data had been collected to get a clear indication of the alternative conceptions within the student population. Individual rather than small group interviews were conducted as the pilot study had indicated that with group interviews the conceptions expressed by one individual may well affect those of other group members.

For this phase of study only audiotaping was used. Although it could be argued that this may have resulted in the loss of some data, there were too many practical difficulties involved in using a video camera at the college for this phase of the research. Furthermore, work with video in the pilot study suggested it offered little if any advantage over audio-taping.

During the first part of each interview subjects were shown a series of eight IAI and IAE cards (Figure 3.2). The first six cards displayed drawings of everyday events in which changes in materials were taking place. These cards were similar to those used by Kruger and Summers (1989), but were presented in an alternative sequence. The two final cards also depicted changes in materials but in a more contrived context.

Table 3.1.

Science Background, Ethnicity and Gender of Pre-Service Primary Teachers involved in the Elicitation Phase of the Main Study. (FF=Fijian female; FM=Fijian male; IF=Indian female; IM=Indian male) (Form 4=Year 10 etc.)

Subject	Science background
FF1	Form 7 Biology
FF2	Form 4 Basic Science
FF3	Form 7 Biology & Chemistry
FF4	Form 4 Basic Science
FF5	Form 7 Biology, Chemistry & Physics
FF6	Form 4 Basic Science
FM1	Form 4 Basic Science
FM2	Form 4 Basic Science
FM3	Form 4 Basic Science
FM4	Form 4 Basic Science
FM5	Form 7 Biology & Chemistry
FM6	Form 7 Biology
IF1	Form 4 Basic Science
IF2	Form 6 Physics
IF3	Form 7 Biology, Chemistry & Physics
IF4	Form 7 Biology, Chemistry & Physics
IF5	Form 4 Basic Science
IF6	Form 7 Biology, Chemistry & Physics
IM1	Form 7 Biology, Chemistry & Physics
IM2	Form 6 Physics
IM3	Form 6 Biology & Chemistry
IM4	Form 7 Biology & Chemistry
IM5	Form 4 Basic Science
IM6	Form 7 Biology, Chemistry & Physics

To begin the interviews a series of focus questions were asked about the drawings on the cards. For example the focus questions used with card 2 from Figure 3.2 were:

1. What has happened to the water in the puddles?

2. Where has it gone?

3. Why does this happen?

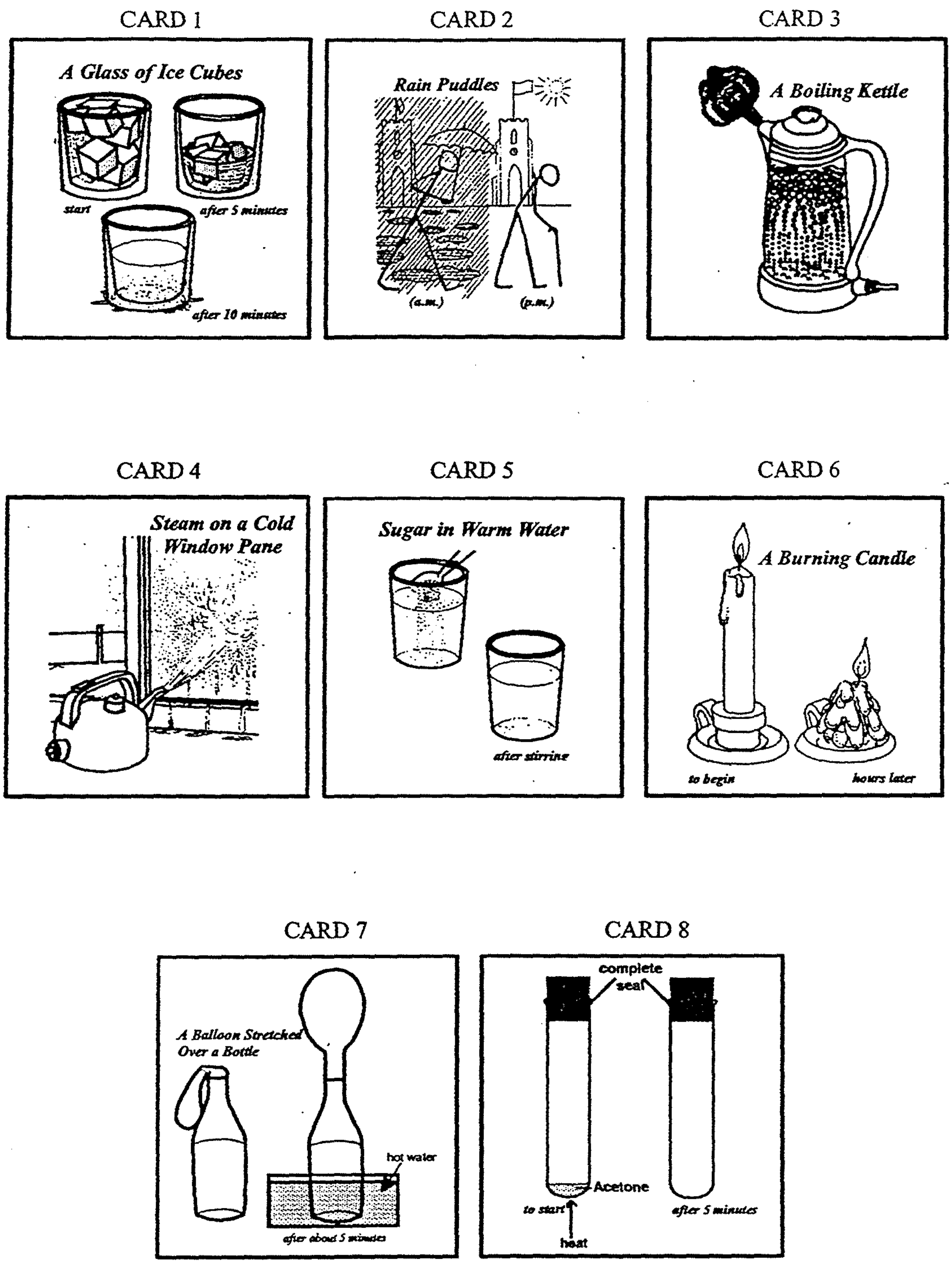


Figure 3.2. Cards used in the interviews with the student teachers during the main study.

Further questions were then framed according to the responses until the expression of student's ideas had been exhausted. In each case students were asked to provide the best scientific explanation they could for the various phenomena.

The second part of each interview involved the use of the prediction-observation-explanation technique with five practical activities. These activities included:

1. Depressing syringes filled with air and water.
2. Submerging in water an inverted glass which contained compressed cotton wool in its inner base.
3. Using body heat to warm a gas thermometer comprising a conical flask and delivery tube containing a bead of water.
4. Inserting a heated metal ball through a ring.
5. Operating a set of model lungs.

This range of cards and activities was used to determine whether the students could apply Kinetic Theory consistently when explaining a variety of phenomena involving changes in matter. Thus they provided the opportunity to probe the students' understanding of change of state, conservation of matter, solubility, heat and pressure, all concepts to which Kinetic Theory can be applied. Each interview lasted approximately 75 minutes and was conducted in English which is well spoken and understood throughout Fiji.

Analysis and validation of the data from the elicitation phase

The tapes of the interviews were transcribed and the transcripts were printed in reduced form on the left of the page with a blank space on the right for comments. This space was divided into two columns, one labelled interpretation and the other classification. The interpretation column included a description of the subject's reasoning, assumptions and the concepts displayed. In the classification column, the concepts were classified as scientific or alternate. This approach to the analysis was similar to that described by Erickson (1979). This analysis formed the basis for the compilation of the Concept Profile Inventories (CPI) described below.

Concept profile inventories

Concept Profile Inventories, which were first described by Erickson (1979, 1980), are one way of representing the pattern of beliefs about a certain phenomenon, expressed by a particular subject or group of subjects. For each interview a list of concepts is compiled. The concepts from all the interviews are then collated and classified in a CPI. The inventory is a systematic list of the accepted scientific and the alternative concepts held by those interviewed. This approach to data representation has been employed in a non-Western context by Rice (1991) in Thailand and Rollnick and Rutherford (1990) in Swaziland. An example from the work of Rollnick and Rutherford (1990) on air and pressure with Swazi primary teachers is shown in Table 3.2.

Table 3.2.

A Segment from a Concept Profile Inventory (Rollnick & Rutherford, 1990).

Conceptions showing that air exists
Scientific conceptions
'Empty' containers contain air.
There is air in the bottle-S1 (S=Student)
Bubbles coming from an 'empty' container are air.
Air came from the bottle-S1
Alternative conceptions
'Empty' containers have nothing in them.
The bottle is empty-S2
The bubbles are air getting in-S9

Note: Bold type represents the researcher's assertions of scientific and alternative conceptions from interviews.

Similar CPIs were constructed for the two ethnic groups within the college population in Fiji. This facilitated the comparison of scientific and alternative conceptions held by Indians and Fijians.

Validation of interview analysis

The outcomes of the interview analysis were validated using the method described by Rollnick and Rutherford (1990). Two sample interviews were sent to each of six judges, all of whom were science educators. The judges were asked to analyse the transcript and code those conceptions they believed were represented in each of the interviews. To do this they used the coding scheme provided in the CPI. The results from the judges were compared with the analysis of the researcher and the percentage agreement for each concept calculated. An agreement on the classification of concepts of 75% or more, as used by Rollnick (1988) was considered a satisfactory indication of the validity of the analysis.

Additional information from the elicitation phase

Once the conceptual understanding component of each interview was completed, supplementary information was sought on the students' views about the nature of science, the science classroom environment and finally traditional beliefs they held which might conflict with the scientific view. To this end the subjects were asked about specific traditional beliefs and how they reconciled these with the explanation presented by science. This component of the interview was semi-structured and guided by some questions adapted from the Constructivist Learning Environment in Science (CLES) instrument developed by Taylor, Fraser and White (1994), and the Socio-Cultural Environment Scale (SCES) developed by Jegede and Okebukola (1988).

3.4.2 The prevalence phase

This phase of the research was designed to address the second research question outlined in the introduction, namely: *How prevalent are these alternative conceptions within the two major ethnic groups which make up the target population?*

The aim of this phase of the research was to determine how widespread specific alternative conceptions were within a much larger sample of the college population. It was also intended to give some indication of the relative prevalence of these conceptions within the two major ethnic groups. Such information was necessary if an assessment was to be made of specific concepts, within the broader conceptual area of matter and how it changes, which students found most difficult to understand.

3.4.2.1 Data collection methods for the prevalence phase

The time consuming nature of in-depth interviews makes this method inappropriate for determining how prevalent different conceptions are in a wider population. Thus, as Gilbert et al. (1985) suggest, it is only possible to check if the patterns of student understanding identified by interview are replicated over large sample sizes using a survey instrument. To do this, a limited number of possibilities is available. The use of open-ended questions (Ginns & Watters, 1995) may be employed in large scale surveys. This approach not only allows subjects to provide quite detailed responses to questions, but also it can be used to make comparisons between subgroups, as the data can be coded and quantified. Having said this, only a limited number of questions can be used with such an instrument, and significant time is required to analyse and quantify the data when the sample is large.

Perhaps the most common form of survey instrument used to determine prevalence of alternative conceptions is the multiple choice test (e.g., Helm, 1978, 1980; Ivowi, 1984; Linke & Venz, 1978, 1979; Watts & Zylbersztajn, 1981). This approach was first proposed by Tamir (1971). He believed that those constructing multiple choice tests usually provided alternatives (or options) based on their own associations, idiosyncrasies and thought patterns. Tamir felt that a more effective method of test construction was to use students' alternative conceptions gleaned from their answers to open-ended or essay type questions. In his view, since the major objective of testing was to detect the misunderstandings and misconceptions of students, then it seemed logical first to ask students for alternative answers and use them to construct multiple choice tests accordingly.

This approach has been embraced by many workers researching into alternative conceptions and a number of studies have used interviews rather than open-ended questions to provide the necessary material for the tests (e.g., Linke & Venz, 1978, 1979; Rollnick & Rutherford, 1990; Summers & Kruger, 1994). Other researchers have made adaptations to Tamir's original model. Watts and Zylbersztajn (1981) used a combined multiple choice/explanation format to survey 125 students' understanding of forces. This modification is intended to provide the tester with a richer understanding of the students' responses. Treagust (1986, 1988) and Haslam and Treagust (1987) have described a more sophisticated two-tier multiple choice instrument for diagnosing students' alternative conceptions. Their format requires subjects to select an answer from the first tier and select a justification from those provided in the second tier.

While the use of a multiple choice instrument offers a number of advantages, particularly in terms of ease of marking, coverage of content and the ability to compare group performance, this type of instrument also has certain limitations. Good multiple choice questions are often difficult and time consuming to construct, and as Bar and Travis (1991) point out, the alternatives offered in multiple choice tests may act as a source of alternative conceptions not previously held by subjects, particularly if they appear to be 'scientific.' This view is similar to that of Strike and Posner (1992) who, as mentioned earlier, argue that many alternate conceptions may be triggered spontaneously in response to a problem. Clearly, the outcome of any survey based on objective items requires careful interpretation as the possibility of 'generated' alternative conceptions may produce misleading findings.

Other researchers have opted for a true/false format (e.g., Kruger et al. 1990b; Hewson & Hewson, 1983) to survey alternative conceptions in a large population. While true/false items have many of the advantages and limitations pointed to for multiple choice items, they reduce the number of options which need to be generated in each case. An additional drawback, however, with a true/false format is that since only two choices are possible, the uninformed student has a fifty-fifty chance of guessing the answer. This can limit the range of scores on the test and thus reduce its effectiveness as a measuring instrument. The use of two choices poses other problems. When students mark true statements false, there is no means of determining what alternative conception they had in mind, thus the true/false item lacks the diagnostic features of the multiple choice item, where the selected alternative provides clues to the alternative conceptions held by students. Also when students correctly mark a false statement false there is no assurance that they know the true version of the statement. However, as Gronlund and Linn (1990) point out, when only two responses are possible, the true/false item or some adaptation of it should be used, as this is likely to provide the most effective measure.

Implementing the prevalence phase

It was originally intended to develop a multiple choice instrument for the prevalence phase of the study using data from the CPIs constructed from the elicitation phase. However, after studying the CPIs for both groups, it became apparent that there would be considerable difficulty in generating three or more options for many of the intended items since a large number of the statements to be drawn from the CPIs had only two possible responses. Thus, despite the limitations associated with a true/false format, it was considered the most practical alternative available for the large scale survey.

Items for the Science Concept Survey (SCS) were constructed in accordance with guidelines provided by Gronlund and Linn (1990) for developing unambiguous true/false items. These used illustrations from the IAI cards and POE activities with accompanying statements being taken and adapted from the CPIs. In an attempt to overcome some of the limitations outlined above, students were provided with three possible responses to each item, 'true'; 'false' and 'not sure.' Each item also comprised a free response section to allow for justification of the answer chosen. These additions were aimed at reducing the incidences of guessing and also provided the researcher with data to construct a richer understanding of the subjects' responses. All of the participants had previous experience of this item style which is used extensively in examinations in Fiji.

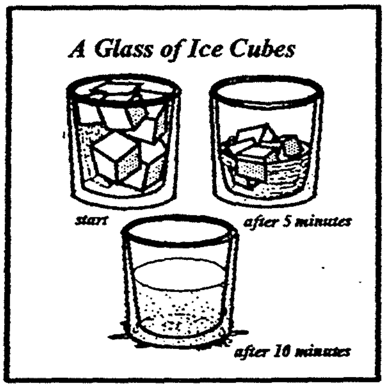
In a further attempt to reduce the incidences of guessing and reduce anxiety amongst the subjects, the following instructions were provided with the SCS:

> Please note this is **not** a test. This is a survey to help in the preparation of new teaching materials for you to learn from. For each statement, circle the response you feel is appropriate. If you are not sure about the answer, circle **'not sure'** rather than guessing. Please give a reason for the response you have chosen.

These points were emphasised by the researcher during the administration of the SCS instrument.

The final instrument consisted of fifty items. An example of an item is provided below and the complete instrument is presented as an appendix (see Appendix A).

The drawing on the right shows ice cubes in a glass at the start then after 5 and 10 minutes. Use these diagrams to answer questions 1-4.



3. The water droplets on the outside of the glass after 10 minutes have come from the atmosphere.

true   false   not sure

Reason:____

____

Figure 3.3. An example of an item used in the survey for the prevalence phase.

As part of the development process the SCS was trialed with a first year class of 29 students of whom 15 were Indian and 14 were Fijian. When the test was completed a response frequency table was compiled. This highlighted items where a large number of students had chosen the 'wrong' option. The free responses which accompanied these items were carefully examined to determine whether this was due to a high prevalence of alternative conceptions or a poorly worded items. On the basis of this trial a number of the questions were altered and additional labels were added to some of the diagrams. For example, item 2 originally read 'The particles which make up the ice cubes are constantly moving', a number of students chose the 'false' option for this but responded that the particles were not moving, only vibrating. This suggested that the term movement had been interpreted as free movement, rather than movement around a fixed point. Thus the item was reworded accordingly.

The SCS was administered to the entire second year cohort (144 students). Since the intake to the college was based on a racial and gender quota system aimed at obtaining approximately equal representation of both sexes and of both major ethnic groups this cohort provided a representative sample of the total college population and negated the need to carry out stratified sampling. As a result there was almost equal representation of both major ethnic groups with 73 Indian students and 70 Fijian students completing the survey (one Fijian student was absent). No time restriction was placed on the completion of the SCS.

The instrument also acted as the pre-test, and subsequently as the post-test, for those students who participated in the experimental phase to be outlined later.

Representation of data from the test

The student responses to the test items were plotted graphically to indicate the frequency of response to each option within the SCS. Rather than plotting all of the data on one graph, they were graphed according to the five major categories within the CPI. This allowed for easy identification of the most prevalent alternative conceptions within the general population. Similar plots were undertaken for the two major ethnic groups. This made it possible to determine whether certain alternative conceptions were more prevalent within one group compared to the other, and as such reveal particular areas of weakness.

Content validity

To ensure the SCS had content validity, it was submitted to six judges, all of whom were science teachers, along with a copy of the CPI developed from the interviews. The judges were asked to match each survey question to a specific subcategory within the CPI. The same task was carried out by the researcher and the results compared. The judges were also asked to check for ambiguities of wording in the survey items. The results of this validity check are reported in chapter 6.

Reliability

In other circumstances, test reliability would be determined using a test-re-test correlation, but given the dual role of the SCS as pre-test and post-test, the risk of students becoming familiar with the test was considered to be unacceptably high. Furthermore, Helm (1978, 1980) has pointed out that calculating any measure of reliability for a misconceptions test or survey serves no purpose, and cites a number of reasons for this:

1. The test is criterion-referenced rather than norm-referenced; that is, it is not designed to discriminate between candidates but to establish whether or not they are capable of carrying out certain tasks, and it is generally agreed that traditional techniques of item analysis are inappropriate to criterion referenced tests;

2. The concept of internal consistency is of dubious relevance to this kind of misconceptions test.

It is of interest to note that, apart from Helm, other workers such as Rollnick (1988) and Za'rour (1975) who have used similar surveys to determine the prevalence of alternative conceptions within large groups have made no attempt at any estimate of reliability.

No estimate of reliability was calculated, as the survey in this study was intended to discover whether or not certain alternative conceptions were widely held, and as such interest lay in the answers to particular questions and especially in the popularity of a chosen option rather than in overall scores.

3.4.3 The experimental phase

This phase of the research design addressed the third question outlined in the introduction to this chapter, namely: *Can a teaching approach based upon a constructivist view of learning effect improved conceptual understanding of Kinetic Theory and changes in matter in the target population?*

The aim of this phase of the research was to undertake an intervention with an experimental group of students. The intervention (or treatment) involved using a constructivist approach to learning about changes in matter and Kinetic Theory. Thus it employed strategies based on a constructivist view of learning which are well established in the literature. The outcome was compared to that of a control group of students, taught the same topic, using the more traditional approach normally employed at the college (The specific teaching methods used with the control and experimental groups are discussed in detail in chapter 5). To this end a quasi-experimental design was utilised. According to Campbell and Stanley (1963) quasi-experiments constitute a class of empirical studies with humans, which lack two of the usual features of experimentation: they rarely occur inside a laboratory, and they never involve the random assignment of units to the treatments being contrasted. Their function is to probe causal relationships between manipulated independent variables (treatments) and measured outcomes (Cook, 1983). A number of quasi-experimental designs are available (Cook & Campbell, 1979). However, for the purposes of this study the pre-test/post-test non-equivalent groups design was the most appropriate. This was because such a design is typically used in school or college situations where, for reasons of college organisation, such as time-tabling, teaching groups are normally fairly rigidly established. Thus it is not possible to conduct a true experiment, due to the problems of assigning subjects randomly to the control and experimental groups. Often in a school or college setting (as was the case in Lautoka Teachers' College) it is necessary to use groups as they are already established, such as in classes or year groups. Having said this, the design mentioned above allows for the control of as many variables as possible within the constraints of a college system.

	Pre-test Treatment Post-test
Control Group	Y1-------------------------Y2
Experimental Group	Y1----------X-------------Y2

Figure 3.4. Pre-test and post-test comparison (non-randomised) (Y=group mean score) (After Burns, 1994)

A quasi-experimental design involving pre-test/post-test non-equivalent group comparison is summarised in Figure 3.4.

Thus quasi-experimental designs provide control of when and to whom measurement is applied but, because random assignment to experimental and control treatments has not been applied, the equivalence of groups is not assured.

With this design, both the experimental and control groups take the same pre-test and post-test, and typically the researcher teaches both groups for the same time period. The difference in mean scores between the post-test and pre-test (Y2 - Y1) may then be found for each group and then these differences tested for significance in order to ascertain whether the experimental treatment produced greater change than the control situation. Such a comparison is considered justifiable, despite the possible lack of group equivalence, because this design may be the only one feasible in the circumstances. However, Best and Kahn (1989) have cautioned that the results obtained from this type of non-equivalent groups design should be carefully interpreted.

In this study, pre-test scores were used to determine the absence of any significant difference between the control and experimental groups prior to treatment. In subsequent analysis a more powerful strategy was employed in which pre-test scores were used as covariates, rather than calculating and comparing gainscores as advocated above.

For the purposes of the teaching experiment which was involved in this research project, two classes of students were randomly selected from those classes available by the throw of a die (there being 6 possible groups). These were in turn randomly assigned as the control and experimental groups for the study by tossing a coin. The experimental group contained 26 students (6 Indian females, 7 Indian males, 7 Fijian females and 6 Fijian males). The control group contained 23 students (6 Indian females, 8 Indian males, 3 Fijian females and 6 Fijian males). The intervention lasted for six weeks, and each group received three hours of instruction per week.

The post-test

Immediately after the teaching experiment, both the control and experimental groups completed the SCS as the post-test. This was identical to the pre-test, as it was considered that altering the wording of questions to reduce the sensitisation effect could make the results too difficult to interpret. This test was analysed using a Two Way Analysis of Variance (ANOVA) *(SPSS, 1993)*, with pre-test scores as covariate, to determine if there were significant differences in performance between the control and experimental groups and between the two major ethnic groups before and after instruction.

Delayed post-test

Ten weeks after the post-test had been completed by both groups, a delayed post-test was administered. This contained only 11 of the original 50 items of the SCS which comprised the pre- and post tests, as at the time students were about to sit for their final college examinations. In these circumstances, a longer test was deemed inappropriate. The items selected for inclusion in the delayed test were 2, 4, 6, 7, 8, 21, 29, 39, 44, 49 and 50, as it was these items in which a large disparity had occurred between the groups on the post-test. The selected items also covered all of the conceptual areas covered during the teaching intervention with the exception of pressure.

The delayed post-test was intended to determine whether the difference in performance on these items had persisted or had diminished appreciably with time. As with the post-test, the delayed post-test was analysed using a two-way ANOVA to determine if a statistically significant difference existed between the mean scores for both groups.

3.4.4 The evaluation phase

This phase of the research design addressed the final research question, namely: *Will teaching based upon a constructivist view of learning prove to be appropriate for use with both ethnic groups?*

In order to complement the quantitative findings of the teaching experiment, a qualitative evaluation phase was incorporated into the research design. This revealed important details about what happened during the intervention, and how individuals from the different ethnic groups reacted to the different teaching strategies employed. As mentioned earlier, this use of qualitative and quantitative data collection methods within a single study has been advocated by a number of researchers (e.g., Cizek, 1995; Goodwin & Goodwin, 1984; Niaz, 1997). They believe that it provides increased comprehensiveness of findings by supplying the context of meaning in which the quantitative findings can be understood.

As part of this phase ran in parallel with the teaching experiment, the data obtained were fed back into the experiment and used to modify the teaching strategies when it was deemed appropriate.

The evaluation was conducted at two levels:

1. Through the monitoring of the ongoing intervention.
2. Through terminal interviews with subjects from the experimental and control groups.

Monitoring of the ongoing intervention

The monitoring was used to establish how the experimental and control groups responded to their respective methods of instruction and, in particular, if certain of the experimental strategies led to a better understanding of specific science concepts. To this end both control and experimental classes were video and audiotaped throughout the intervention. The views of the normal class lecturer, who acted as an independent observer for both groups, were also sought. The monitoring process is discussed in more detail in chapter 5.

Terminal Interviews

At the conclusion of the intervention, twenty seven individual interviews of approximately 40 minutes each were conducted with experimental and control group subjects who volunteered. The interviews were semi-structured and intended to serve two purposes. Firstly they provided an opportunity for a final probe of understanding, and thus some corroboration of the scores obtained in the post-test. To this end the first part of each interview was devoted to obtaining explanations of a number of the IAI cards and POE activities used in the elicitation phase. As a result of time constraints, it was not possible to use the full range of cards and activities during these interviews, thus cards 1, 2, 3 6 and 8, along with the air thermometer and model lungs, were used to probe understanding in these final interviews. It was considered that these cards and activities covered a wide enough range of concepts to provide an effective check on the students' understanding of the topics covered in the intervention. During the second part of each interview subjects were asked to make explicit their views on the teaching strategies employed throughout the intervention, and in particular which strategies they found most effective. Subjects from the experimental group were also asked to compare the instruction they had received with both their previous experiences of science at the college and at school. This approach was adopted by Jegede and Okebukola (1991b) and Summers and Kruger (1994) when attempting to evaluate the effectiveness of their teaching interventions.

Summers and Kruger, in particular, obtained valuable qualitative data on teachers' perceptions of their training program from post-intervention interviews. In these interviews teachers recalled many aspects of the training which they thought had enhanced their understanding. The information obtained was of particular interest in this study because, for cultural reasons, it was anticipated that Fijians and Indians might react quite differently to different teaching strategies. Thus, as with the initial interviews, participants were selected so as both ethnic groups were suitably represented. As such, twenty subjects from the experimental group took part in the terminal interviews (5 Indian females, 5 Indian males, 7 Fijian females and 3 Fijian males) while seven control subjects were also interviewed (2 Indian females, 2 Indian male, 2 Fijian females and 1 Fijian male).

Since it was considered important to obtain as much feedback as possible on the teaching strategies employed with the experimental group in the limited time available towards the end of the study, more interviews were conducted with subjects from this group. This explains the disparity between the two groups in terms of the numbers of subjects interviewed. Figure 3.5 summarises the overall design of the project, while Table 3.3 provides a detailed overview of the timing of the study within the context of the academic year at Lautoka Teachers' College.

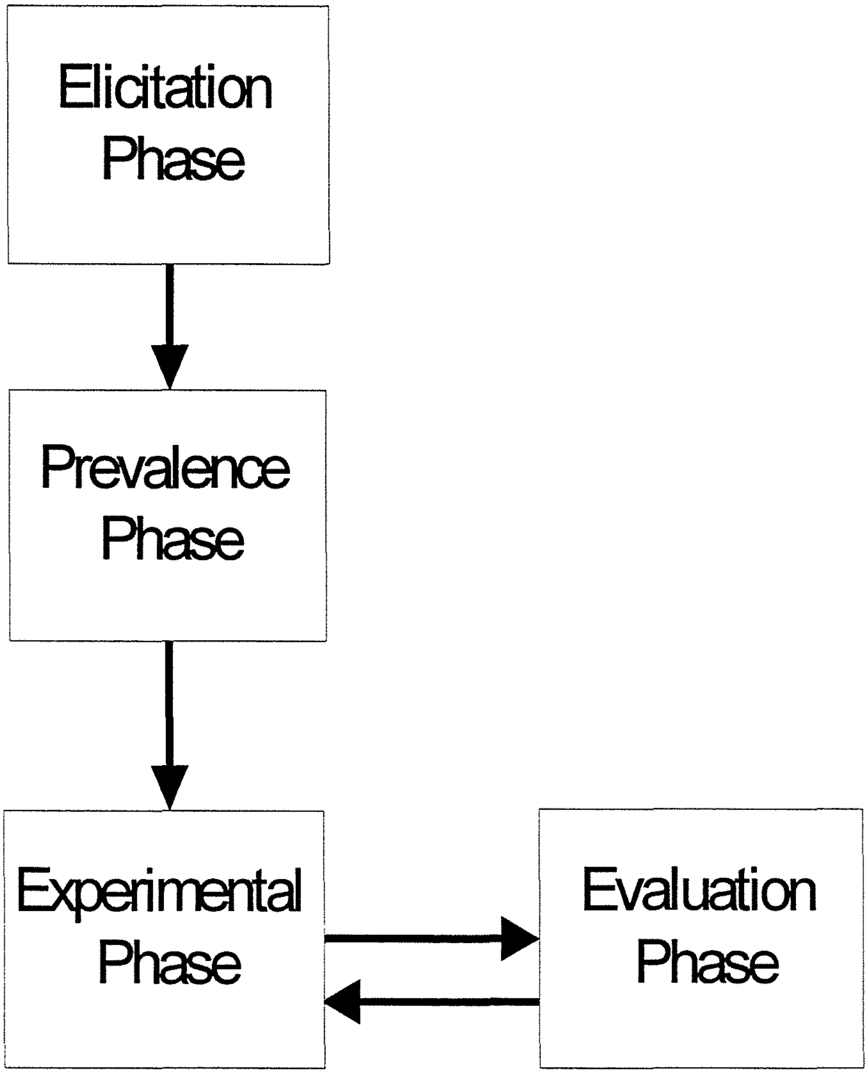


Figure 3.5. Project design, showing the interaction between the different phases.

Table 3.3.

The Sequence and Timing of the Data Collection Activities Undertaken during the 1996 Academic Year at the Lautoka Teachers' College.

Timeline of study and major events in the college calendar	Data collection and other activities undertaken during the study
Late January	Preliminary inventory of resources. Assembly and/or construction of equipment required for POE activities of Elicitation Phase.
1 Feb. - 8 March	Elicitation Phase - Twenty four interviews employing IAI and POE techniques.
11 March - 30 April (Second year teaching practicum)	Analysis of Elicitation data and construction of CPIs for both ethnic groups. Validation of Elicitation Phase analysis. Construction and validation of SCS. Piloting of SCS with first year students (n=30), and subsequent modification.
1 May - 17 May	Administration of SCS to entire second year group (n=143).
20 - 24 May	Selection of control and experimental groups for teaching experiment. Discussion of Constructivist View of Learning and associated teaching strategies with experimental group.
27 May - 6 July (College mid-year examinations and semester break)	Marking and analysis of SCS. Validation of marking procedure. Preparation of lesson outlines and resource materials for teaching experiment.
9 July - 23 August	Teaching experiment. Transcription of group discourse from control and experimental small group activities. Post-test administration.
25 August - 13 Sept. (Mid semester break - 25 August - 2 Sept.)	Marking and analysis of post-test. Post-intervention interviews with experimental and control group students.
16 Sept. - 14 Oct. (Final second year teaching practicum)	Transcription and analysis of post-intervention interviews.
14 Oct. - 1 Nov.	Final post-intervention interviews.
5 - 8 Nov.	Administration of delayed post-test. Marking and analysis of delayed post-test.
11 - 22 Nov. Final college exams and graduation.	Transcription of final post-intervention interviews.

3.5 Target group of the main study

The target group for this study consisted of those students undertaking their second and therefore final year at the Lautoka Teachers' College. This represented a group of 150, out of a total college population of over 300. Intake into the teacher education program is based on the students' performance in the Fiji Form Seven (Year 13) Examination, and an interview which every prospective candidate must undergo. However, the college also operates a quota system, which ensures, as far as possible, racial and gender parity in the intake. To enrol at the college, all applicants must have reached a minimum age of seventeen years, and be under the maximum age of thirty three years on or before the 1st June of the year of enrolment (Fiji Ministry of Education, 1992).

The science background of the students varied. All students had completed the Elementary Science course (Years 1-6) and the Basic Science course (Years 7-10), both of which are compulsory. However, beyond this, science in Fiji is non-compulsory, although most students undertake one science subject in their final three years of schooling. Biology and chemistry were the main subjects of choice at this level amongst students arriving at the college, with physics being less popular. Table 3.4 provides more detailed information on entrants' science backgrounds for 1995, the year of entry for participants in this study.

The decision to target second year students was taken because these students were undertaking the compulsory SC24C course-Curriculum Studies in Science II. This involved the use of Basic Science materials and will be described in chapter 5. By this stage all students had completed SC12C Curriculum Studies in Science I which is based on the conceptually less demanding Elementary Science course. A list of the objectives from the Basic Science course which are pertinent to this study and which the college students may ultimately have to teach, is given in the next section.

Table 3.4.

Percentage of 1995 Entrants Holding Passes in Various Science Subjects at Fiji School Leaving Certificate (FSLC) and Form 7 Level. (Based on a random sample of 70 entrants)

Science subject	Year 12 (FSLC)	Year 13 (Form 7)
Biology	45	38
Chemistry	50	40
Physics	28	28

3.6 The pilot study

A pilot study was undertaken in Australia at the School of Mathematics, Science and Technology Education of the Queensland University of Technology (QUT). The aim of this study was to trial and refine the research methods to be used in the Elicitation Phase of the main study, namely IAI, IAE and POE. The pilot study also afforded the researcher experience in using these probes of understanding. Data obtained from the pilot study were used to compile a CPI for the Australian students interviewed. This proved to be of value later as it allowed for qualitative comparisons of alternative conceptions found amongst students from a Western society, with those found amongst the more traditional Indian and Fijian communities in Fiji. The details and findings of the pilot study are reported in chapter 4.

3.7 Defining the conceptual area of the study

The initial phase of this project probed the understanding that Fiji pre-service primary teachers have of Kinetic Theory, and also explored to what extent they could apply this theory to explain changes in matter. Specifically, this included their understanding of: matter and how it changes; solubility; heat and pressure. All of these topics are covered in Years 7 and 8 of primary schooling in Fiji as part of the Basic Science program. In order to define the conceptual area of the study more rigorously, the specific objectives from the Basic Science course, which relate directly to these topics, were identified and listed (see Appendix B). Having identified these objectives, it was appropriate to determine the underlying scientific principles which informed them. It was considered that if teachers had a sound understanding of these principles they would be better able to help their students acquire a conceptual understanding. This was particularly true if they were to answer children's questions and encourage discussion in their science lessons. These scientific principles defined the conceptual area which was probed for understanding with the pre-service teachers in Fiji and Australia. They are listed below the course objectives in Appendix B.

3.8 Summary

Chapter 3 has outlined the four main questions this study was intended to address, along with some of the theoretical considerations which underpinned them. The utilisation of a mixed methodology in the design of the study has been justified, and the individual methods within the design which were used for data collection have been detailed. The following chapter describes a pilot study undertaken in Australia, which enabled the researcher to become familiar with and confident in the use of the IAI and POE methods employed in Phase 1, the elicitation phase. It also afforded the opportunity to complete some analysis of interview data collected using these techniques, and resolve any potential difficulties before embarking on the main study in Fiji.

Chapter 4

The Pilot Study

4.1 Introduction

As mentioned in chapter 3, a pilot study was carried out in Australia in advance of the main study in Fiji. For practical reasons the pilot study was conducted in a Western context with students undertaking the foundation year of a Bachelor of Education Degree (BEd) in Early Childhood Education at the Queensland University of Technology. These students generally enter the university directly after high school at the age of seventeen and are predominantly, although not exclusively, female. A number of mature age students also undertake this course. Background in science varies considerably. Most students would have completed a general science course in Year 10 of high school. However, after that science is not compulsory and, while most students would have studied one science subject in Years 11 and 12, some would have studied two and others none.

Table 4.1 gives an indication of the science background of students undertaking the first year of the course in 1995.

Table 4.1.

B.Ed Foundation Students' Science Background for Years 11 and 12 of High School.

(Data from Semester 2, 1995)

Total Number	Biology	Chemistry	Physics	Multistrand Science	No Science
113	63	22	13	17	33

From the table it is apparent that many of these students have a relatively weak background in physical science, with only 31% having completed physics and/or chemistry at Years 11 and 12 of high school, while 29% had taken no science at this level.

The main purposes of the pilot study were threefold.

1. To provide the researcher with experience in conducting interviews using the specific data collection techniques of Interviews-about-Instances, Interviews-about-Events and Prediction-Observation-Explanation. These techniques would be used in the elicitation phase of the main study and have been reviewed in chapter 3.

2. To provide the researcher with the opportunity to analyse the data from the interviews and explore methods of categorisation for constructing a Concept Profile Inventory for the group of pre-service teachers involved in the study.

3. To allow the researcher to establish the most appropriate procedure for conducting the interviews in terms of the sequencing of cards and demonstrations, the use of video or audiotaping for data collection and effectiveness of single subject interviews as against interviews with small groups of subjects.

The pilot study also yielded information on both the scientific and alternative conceptions which a group of Western pre-service teachers held about changes in matter and to what extent they could apply Kinetic Theory to explain these changes. These findings are reported as part of this chapter.

4.2 Subjects of the study

Ten pre-service teachers took part in the pilot study which was conducted during the second semester of 1995. These subjects were all volunteers and included nine females and one male. The science backgrounds of the individuals varied and these are summarised in the Table 4.2.

4.3 Data collection methods

Initial interviews were conducted with all ten subjects prior to their course of instruction on matter and Kinetic Theory. During the first part of each initial interview subjects were shown the series of eight cards depicted in Figure 3.2 of section 3.4.1.1.

Table 4.2.

Science Background of the Student Teachers involved in the Pilot Study

Subject	Science background (Years 11 & 12)
S1	Biology
S2	Biology (not completed)
S3	Biology, Chemistry, Physics
*S4	Biology (failed)
*S5	Biology (failed)
*S6	Biology
*S7	Biology, Chemistry, Physics
S8	Biology
S9	Biology, Chemistry (failed)
S10	No science

Note The participants included four mature age students (over 25 and indicated *) who had not studied science for some time.

Interview-about-instances and interview-about events techniques (Osborne & Gilbert, 1979, 1980 a and b) were used in the initial phase of the interviews. The second part of the interview involved the use of the prediction-observation-explanation technique which, as mentioned previously, involved the five practical activities below:

1. Depressing syringes filled with air and water.

2. Submerging in water an inverted glass which contained compressed cotton wool in its inner base.

3. Using body heat to warm a gas thermometer comprising a conical flask and delivery tube containing a bead of water.

4. Inserting a heated metal ball through a ring.

5. Operating a set of model lungs.

Each interview, which was either audio or videotaped, lasted approximately forty minutes.

A series of post-instruction interviews were conducted with four subjects who appeared, from the initial interviews, to have no coherent particulate view of matter. These subjects had great difficulty explaining the changes in matter presented in the initial interviews at anything other than a macro-level. In other words they could, in general, only describe the surface features of the changes taking place and were unable to explain these at a molecular level. During the post-instruction interviews, subjects were presented with their own individual profiles extracted from the Concept Profile Inventory (described below), and asked to comment on the statements they had made. This provided some insight as to whether or not their understanding had changed and what aspects of their instruction they had found most helpful.

4.4 Data analysis and development of a Concept Profile Inventory

Because of time constraints associated with the pilot study, a shorthand version of the analysis detailed in chapter 3, section 3.4.2 was employed. Thus each transcript was carefully examined for statements which could be construed as evidence of the subject's underlying beliefs about matter. These beliefs or conceptions were classified as 'scientific' or 'alternate' and were then organised into five major content-orientated categories. The five categories included conceptions about change of state, physical and chemical change and conservation of matter, pressure, heat and solubility. These five categories formed the basic structure of the CPI.

Although the categories are not mutually exclusive and involve some content overlap, they were considered to offer the best arrangement for organising the subjects' conceptions, without making the CPI too complex. Once this gross structure had been established, the subjects' conceptions, both 'scientific' and 'alternate', which were taken verbatim from the transcripts, were inserted into the CPI. The researcher's assertions of these scientific and alternate concepts provided subcategories and thus greater internal structure for each of the major content categories. The categories and subcategories were then coded using a system of letters and numerals.

4.5 Pilot study findings

The research findings reported below are divided into two sections. The first of these concentrates on the effectiveness of the data collection and analysis procedures and includes modifications implemented in the main study. The second section reports on the conceptions which the subjects of the pilot study held about changes in matter and to what extent they could use Kinetic Theory to explain these.

4.5.1 Findings on the applicability of the data collection procedures

4.5.1.1 Interviews-about-Instances and Interviews-about-Events

As White and Gunstone (1992) point out, the distinction between instances and events is often somewhat blurred. This proved to be the case with the study reported here, as the focus questions used with each card required subjects not only to recognise the presence of certain concepts such as evaporation, but also to explain them e.g., focus questions used with card 1:

1. Have any changes of state taken place in this picture?

2. What changes have occurred?

3. What happens during melting?

4. Where has the water on the outside of the glass come from?

5. Why has this happened?

This distinction did not appear to be particularly important in terms of the efficacy of the procedure. In fact the use of cards proved to be an extremely effective method for probing subjects' understanding of how matter changes and revealed to what extent and how consistently students could apply Kinetic Theory when explaining the changes depicted.

In general, the subjects had little difficulty interpreting the illustrations presented on the cards including the final two which represented situations unfamiliar to those taking part. The use of focus questions with each card ensured consistency between the interviews and also allowed for further probing of each individual's understanding of a particular phenomenon. Having said this, some difficulty was encountered in trying to determine if subjects held a molecular model without using this or related terminology in the questions. To this end subjects were asked to give the 'most scientific explanation possible' when explaining a particular concept.

The responses of the subjects indicated that the cards were presented as intended with the more difficult examples towards the end of the sequence (Gilbert, Watts & Osborne, 1985). In general, this allowed the subjects to gain some confidence in the early stages of the interview. It was noted that as cards 1 and 3 elicited subjects' views about water in a gaseous state and condensation, card 4, which also depicted the process of evaporation and condensation, yielded little extra insight about the understanding of these concepts. Despite this it was decided to include this card in the main study as it might prove useful in a different context.

4.5.1.2 Prediction-Observation-Explanation

As prediction and explanation require genuine application of knowledge, this technique also proved to be an effective probe of the subjects' ability to apply Kinetic Theory in a variety of contexts. It also afforded the opportunity to explore subjects' understanding of phenomena such as the expansion of solids when heated and the compression of gases and liquids which are more easily demonstrated than depicted on cards. In fact all five of the demonstrations used during this section of the interview were straightforward to set up and execute, and were consistent in their outcomes. These were important considerations for the main study in Fiji, where availability of equipment is often limited.

The POE procedure differs from IAI and IAE insofar as the subjects are made aware of whether their views are consistent with or at odds with the scientific view. As such the procedure almost inevitably presents subjects with discrepant events. This certainly proved to be the case in this study, where many of the subjects found their predictions at odds with what they observed. This presented them with a cognitive conflict which they were often unable to resolve. The potentially damaging effect of discrepant events on subjects' confidence has already been reported in chapter 2. However, this was not apparent in the pilot study, where individuals seemed to be genuinely interested as to why their conceptions differed from the observed outcomes. This may have been a reflection of their status as pre-service teachers and the fact that they might soon be called upon to teach these concepts during their teaching practicum. Furthermore the non-threatening nature of the interviews in which their ideas were not exposed to a wider audience may also have contributed to their apparent lack of anxiety. Certainly subjects did not appear to be in any way reluctant to volunteer both predictions and explanation.

In some cases the cognitive conflict produced by a discrepant observation resulted in a conceptual change on the part of a subject. This was particularly true of the first demonstration which involved the compression of a gas and a liquid. Here a number of subjects appeared to use a continuous model of matter when making their prediction, often switching to a particulate model to reconcile the conflict between their prediction and observation.

One of the activities, the air thermometer, effectively replicated card 8 of the IAI procedure and as such provided little further insight into the subjects' conceptions of the effect of heat on gases. However, as with card 4, it was decided to include this, at least initially, in the main study.

The first three subjects who were exposed to the POE technique were required to provide their responses in a written form. This is the normal procedure employed when using the technique with a large group (White & Gunstone, 1992). However, the use of a written format in this instance generally resulted in responses which were at best limited in their scope or in some cases difficult to understand. Thus an interview procedure was adopted with the remaining seven subjects. This proved to be much more satisfactory as it allowed for deeper probing of the subjects' understanding.

The range of cards and POE demonstrations provided sufficient stimulus material to determine whether the subjects had an understanding of Kinetic Theory and to what extent this could be applied in different contexts. Thus for any given card or demonstration the subjects' responses could be subdivided into those which indicated no molecular model, those which revealed a partial or inconsistent molecular model and those in which a complete molecular model which encompassed the relationship between particles and energy was used (see Table 4.3). Consequently, the same stimulus materials were employed in the main study.

4.5.1.3 Interview procedures

Certain procedural variations in the interviews were also trialed as part of the pilot study. Thus, during one session, two subjects were interviewed together rather than the normal procedure of interviewing individuals. This approach of using small group interviews was advocated by Rollnick and Rutherford (1990) in their work with African pre-service primary teachers, as it allowed students to enter into discussion about the questions posed. However, it appeared from this pilot study that the conceptions expressed by one subject may have influenced those of the other. For example, during the joint interview with subjects S8 and S9, one subject (S9) introduced a molecular model in an attempt to provide an explanation of melting. The second subject immediately employed a similar model for her explanation.

> S9: Is it something like the molecules coming together or going further apart or something joining them up or something like that?
> S8: And the heats reacting on like the outside temperature reacting on those molecules and making them separate.

Hence it was difficult to establish to what extent the response of one subject influenced the other. For this reason the use of multiple subject interviews were not employed in the main study.

Video and audiotaping were also compared for their appropriateness in recording the interviews. The presence of a video camera did appear initially to have an inhibiting effect on some subjects, but this was fairly transient. Nevertheless, there was no obvious advantage to be gained from the use of video except when more than one interviewee was involved as it was then always clear which subject was responding. Since the decision had been made to conduct individual interviews in the main study, and as audio-taping was more straightforward, only audio-taping was employed during the main study.

4.5.1.4 The construction of a Concept Profile Inventory (CPI)

Developing a CPI for this particular study proved to be a relatively difficult exercise, with the final product being more complex and substantive than other examples from the literature (e.g., Erickson, 1979; Hewson, 1982; Rollnick, 1988). This was mainly a consequence of the broader area of science content under investigation in this research than in the studies cited above. While the studies cited were restricted to relatively narrow areas of content, respectively heat, density and air pressure, the study reported here was concerned with the application of Kinetic Theory over a wider range of topics.

A number of different categorisations were attempted before the final CPI was instituted and as mentioned previously it was not possible to make these mutually exclusive. The range of topics covered during the interviews resulted in a CPI which ran to six pages if all of the subjects' conceptions were included. This format was considered too cumbersome for inclusion in the thesis, particularly as similar profiles would be developed for Fijians and Indians in the main study. Thus the CPI was condensed by providing only a single verbatim example for each conception and indicating the total number of subjects expressing that conception in brackets as suggested by Hewson (1982). The condensed version of the CPI is presented as an appendix (see Appendix C), with the full version being held as raw data.

Once established, the CPI presented a useful composite picture of the subjects' conceptions of various aspects of matter and Kinetic Theory. It also provided a relatively easy means of determining how much conceptual commonality existed between the members of the group interviewed in terms of the frequency with which certain conceptions were held. As each statement within the full CPI was coded according to the subject who provided it, it was possible to extract a profile for any particular individual who took part in the study. This made it relatively easy to identify particular weaknesses in individuals' understanding and to determine the consistency with which they could apply Kinetic Theory to their explanations of different phenomena. The extraction of individual profiles was helpful in structuring the post-instruction interviews.

4.5.1.5 The post-instruction interviews

The use of individual subject profiles provided an effective focus for the post instruction interviews. Subjects were presented with a list of their conceptions both 'scientific' and 'alternate' and were asked to comment on what they had originally said. The cards and demonstrations associated with the particular assertions were also provided as a prompt to memory.

Although these interviews were shorter, as they covered a smaller range of concepts, it was possible to construct a post-instruction CPI for each of the subjects. As this had the same structure as their original CPIs, it was possible to compare their thinking before and after instruction relatively easily and gain some insight as to what extent this had altered (see Table 4.4).

In general, subjects had considerable difficulty identifying specific aspects of the course of instruction which they had found particularly helpful. Three of the four subjects involved in the post-instruction interviews stated that they could not remember anything specific aspect which they had found useful. One subject (subject S5) did make comments about certain activities she had found helpful but these proved to be very vague and she was not able to enlarge on them:

> S5: What we did with the diaphragm thing (model lungs) was good, and the one we did on the vacuum thing (Madgeburg hemispheres) with the particles on the outside. I don't know if it was the experiment itself that was good or because of the explanation, cause I wouldn't have understood it if it hadn't been explained.

This indicated that much more specific questions about each teaching strategy would be required when evaluating the experimental phase of the main study. Simply asking subjects to recall what they found effective did not appear to be a particularly successful approach. For the purposes of the pilot study this was problematic as the researcher was not involved in the teaching of the BEd Science Foundations course and as such was not familiar with all of the instruction the students received.

4.5.2 Findings on the students' prior conceptions about changes in matter

This section reports on the conceptions which the pre-service teachers held about matter and changes in matter. The findings are discussed under the headings of the five conceptual areas presented in the CPI (see Appendix C). Table 4.3 provides a summary of the extent to which the subjects were able to apply Kinetic Theory when explaining phenomena presented in the individual cards and demonstrations. In the extracts from the transcripts included below, **I** refers to the interviewer and **S** to the subject.

4.5.2.1 Conceptions about changes in state

Cards 1 to 4 of the sequence were designed to probe the subjects' understanding on changes in state of matter between the solid, liquid and gaseous phases using everyday examples.

Six of the subjects used the term molecules or particles when describing melting. However, of these, only two were able to provide a complete model of melting which correctly incorporated energy and particles e.g., interview 1.

> I: If they (the molecules) are absorbing heat does that affect them in any way?
> S1: Well it heats the ice cube up so I suppose the molecules might be vibrating more.

More commonly subjects (3) could provide only a partial molecular model which involved a confused conception of the relationship between energy and molecules or did not incorporate energy e.g., interviews 9 and 10.

> I: What actually happens during melting? If I asked you to give a scientific explanation of what was taking place during melting, what would you say?
> S9: Is it something to do with molecules coming together or going further apart or something like that?

> I: What do you think actually happens during melting?
> S10: I'm not really sure, the water particles maybe...something to do with the particles joining together when they're frozen and then they lose their connection when they are water.
> I: Why do you think they lose their connections?
> S10: I'm not really sure of the principles, like I don't fully understand...the ice cubes come out of the freezer all icy and then they melt so maybe the reason that

they aren't connected anymore is that they become invisible. Like when they're together there's a visible thing.

The remainder of the explanations of melting (4) were provided at a macro level with no reference to particles. These students often seemed surprised when asked to elaborate on such terms as melting e.g., interview 7.

I: What do you think actually happens during the process of melting? If you could give as scientific an answer as possible of that what would you say?
S7: That the ice has changed form into water.
I: Do you know why that has happened?
S7: Because of the temperature.

Other subjects attempted more scientific explanations but these were often very confused and appeared to comprise partially remembered information from high school e.g., interview 5.

I: What is happening within the ice during melting?
S5: It's changing its structure...there's a chemical reaction happening because it's changing its form.

Only three of the students made reference to energy and its effect on water molecules when explaining the process of evaporation, two having a conceptual model in close accord with the scientific view e.g., interview 3

S3: They've evaporated (the rain puddles).
I: Why does that happen?
S3: Because the sun heats the puddles and therefore like with the ice cubes, the puddles, the water molecules will heat up and they'll evaporate into a gaseous state and go into the atmosphere.
I: When you say that the sun heats up the molecules, in terms of energy how would you describe what's happening?
S3: I suppose you'd say the sun's energy, I mean the heat energy, its giving off the light energy is being transformed, the molecules are like taking it on, so to speak, and that's activating them and they'll...it makes them move faster, yeah they become more active.
I: So they move faster.
S3: Yeah and they'll just....yeah...they become into a gaseous form as they heat up they gain more energy, they go faster, therefore they just evaporate because they go faster, they leave, they break apart and go into a gaseous state.

As with the explanation of melting one subject incorporated the term molecule into a model of evaporation in which she appeared to view the process as a chemical change involving a change in molecular structure.

Table 4.3.

Pre-Service Primary Teachers' use of Kinetic Theory in Explanations

	Ice in glass	Rain puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	6	3	5	4	5	2	5	5	6	6	1	3	0
Reference to energy	8	7	9	7	2	4	8	3	n/a	10	n/a	8	n/a
Partial molecular model	3	0	0	2	2	0	4	3	2	3	1	1	0
Complete molecular model	2	2	1	0	0	0	1	1	4	4	0	1	0

Interview 5

I: And if they evaporate (the puddles), why do they evaporate?
S5: Because they change their molecular structure, then they get evaporated up into the atmosphere.

While most of the other subjects (5) appreciated that heat energy was involved in the process of evaporation they could only provide a 'macro' explanation of the process e.g., interview 1.

I: Where do you think the puddles have gone?
S1: Oh they've been evaporated by the heat of the sun, into the atmosphere, into the air or whatever.
I: OK if you try to think as scientifically as possible about that, can you say what's happening?
S1: Well the excess water...em...that's been on the ground...em...has been evaporated by the heat of the sun...from the change from a cold overcast day or morning to a hot afternoon.
I: OK, but how exactly does this process of evaporation take place to the best of your knowledge?
S1: Em...I don't know...that's to the best of my knowledge, I can't explain it anymore than I did.

Finally two of the subjects provided an explanation of evaporation which incorporated neither energy nor particles but was based on the idea of absorption e.g., interview 2

I: Do you know how that process (evaporation) takes place?
S2: Em...not really...you mean like the sun being up and absorbing the moisture?

The second of these subjects incorporated the notion of absorption into what appeared to be a partially remembered version of the water cycle e.g., interview 10.

S10: I understand this very well. This is something that they really push in school. I can't actually think of the term, but it absorbs the...doesn't it...it absorbs the water it...em...it's heat takes...the humidity picks up the water basically and then takes it up to the clouds and then the clouds spit it out and then the rain...the sun picks it up and it goes around, but there's actually all scientific terms that I'm not aware of because it's not something I continued through high school with, but I remember learning about it very clearly, so condensation and that type of thing is involved in it.

The process of condensation proved to be even more problematic for the subjects to explain. While all ten subjects were familiar with the term condensation only three associated it with atmospheric moisture and only one was able to relate it to energy loss. However this explanation did not relate energy directly to molecular activity e.g., interview 3.

> S3: Well essentially it's water going into a gaseous form and then coming into its liquid state. Because it goes into a gas it obviously heats up, but then the temperature lowers again so it will come back into a liquid state.

A number of the subjects (4) could provide no explanation for the occurrence of condensation, while others (2) explained it in terms of leakage or some form of residue e.g., interview 1.

> S1: Condensation is just...what would you call it...just residue that's been left on the glass from the evaporation. Or just water droplets that are left or fogging or something like that.

None of the ten subjects appeared to have a complete conceptual model of condensation and no one made any reference to latent heat when attempting to explain changes of state.

Only three of the subjects stated that steam was composed of water in a gaseous state. More commonly subjects (6) viewed the boiling of water as a process involving chemical breakdown of the water molecules. This model of boiling seemed to be based on their knowledge of the formula of water and may have incorporated partially remembered aspects of electrolysis in which the decomposition of water does take place. For example:

> I: What might the gas be (in the bubbles)?
> S1: It would be oxygen as far as I know.
> I: And how would that come about if you're boiling water?
> S1: As water heats up maybe it breaks down part of the water because water is hydrogen and oxygen...so maybe it breaks down part of the water into those different molecules.
> I: So if that was happening would you expect just bubbles of oxygen?
> S1: Logically I suppose there would have to be bubbles of hydrogen as well if both these molecules are in the water formula.

This view was also shared by subject S3 despite the fact that she had successfully completed Year 12 Biology, Chemistry and Physics during the previous academic year.

S3: I suppose I see it as oxygen and hydrogen will break apart into their two separate elements, and that as they cool down...the chances are the oxygen will need to find the hydrogen again and they'll come back together to form the water.

One subject associated the process of boiling with an increase in the number of water molecules while another believed that the water molecules were reduced in size during heating and this was reversed as they cooled.

4.5.2.2 Conceptions about solubility

Card 6 which depicted the dissolving of sugar in warm water was used to probe understanding of solubility. This revealed that none of the subjects was able to provide a complete molecular model of the dissolving process, which involved the breaking of bonds between sugar molecules when the crystals dissolved. In fact only five of the ten subjects made reference to molecules or particles in their explanations.

Two of those who could provide only a macro-level explanation related dissolving to the perceived differential strengths of the substances involved e.g., interview 10.

S10: ...the two separate entities mix together and one is stronger than the other, so one dissolves the other.

Of those who did incorporate molecules or particles into their model of solubility three believed that the sugar molecules were either absorbed by or attached to the water molecules e.g., interview 1.

S1: I'd see the sugar just being attached to the outside or even being absorbed by the (water) molecule itself.

This led the same subject to a view that dissolving was an irreversible process. Most other subjects, however, were able to draw on their own prior experiences to explain how this change could be reversed e.g., interview 3

I: Could you get the sugar back out of the water?
S3: I know you could do it with salt...possibly if you evaporated the water off, the crystals the sugar crystals may come back.
I: So you've done this with salt?
S3: Yes, that's why I thought it might work with sugar even though I've never done it.

Again, although only two subjects were familiar with the term saturation, three others appeared to draw on their own intuition to explain this phenomenon e.g., interview 6

> S6: There's got to be some sort of ratio as to how much sugar can dissolve in x number of mLs of water.

4.5.2.3 Conceptions about gas pressure

Card 7 and demonstrations (1), (2), (3) and (5) were used to probe the subjects' understanding of gas pressure and the nature of gases. All of those interviewed appeared to hold the belief that a gas (in this case air) occupies space insofar as they predicted that the paper in the inverted jar which was submerged under water would remain dry. However, none of the subjects explained this in terms of the air exerting pressure. Most (6) referred to the air forming a barrier which prevented the water from passing. Two of the subjects could offer no explanation for their prediction.

The demonstration with the syringes, in which the participants were asked about the compressibility of liquids and gases, revealed that seven of the subjects believed that a gas could not be compressed. This implied that these subjects had a limited conception of the behaviour of particles in a gas. However, the demonstration itself, as mentioned previously, did appear to effect conceptual change in two of these subjects who proceeded to provide molecular explanation for their observation. Subject S1 claimed that when asked to make a prediction he had not employed a molecular model. Nevertheless his final explanation revealed that he did in fact possess a plausible model for explaining the phenomenon of gas compression.

> S1: I'd assume that in the air syringe there's quite a bit of empty space and some sort of oxygen and carbon dioxide molecules that were loosely packed...and when there was a seal I could push it in. Whereas in the water because it is all molecules which form the liquid you couldn't press the syringe because they already tightly packed into that area.

The concept of a vacuum proved to be extremely counter intuitive. Frequently the term vacuum was used in the wrong context, e.g., interview 1:

> S1: I think the syringe with air in it will form a vacuum and you won't be able to push it closed very easily or not at all.

Even those subjects who from their explanations appeared to have a well established molecular model of a gas still found it difficult to conceive that there is a vacuum between the particles of a gas. Generally when probed further on their understanding of the structure of gases they revealed the belief that some form of matter must exist between the particles, e.g., interview 3:

> S3:...in air there is going to be a fair bit of space and you can push the plunger down and the gas molecules will come together to a point where you can't push them any further 'cause it will consume all the space.
> I: You talk about space between the particles, can you explain that further?
> S3: I want to say it's just the atmosphere, but the atmosphere has molecules in it too...I don't know what empty space would be there is no such thing in terms of molecules.

Only one subject could provide a complete explanation incorporating molecules and energy for the phenomenon depicted in card 7 and demonstrated in the air thermometer. Three of the subjects could provide no explanation while one subject stated that it was due to the gas molecules expanding. Most subjects (6) used the idea that hot air rises as the basis for their explanations. Further probing of this view revealed that it was generally associated with a non-random model of molecular movement within a gas. Thus three of the subjects believed that the majority of air molecules would be concentrated within the balloon after heating.

Finally, all of the subjects had great difficulty explaining the behaviour of the model lungs (composed of a bell jar and balloons). Although two subjects understood that pulling on the diaphragm would decrease the pressure within bell jar, they were unable to extend this into a model of differential pressure in which air was forced into the lungs. Perhaps not surprisingly, in view of the everyday usage of the term, three subjects suggested that air was sucked into the balloons e.g., interview 7

> S7: You're creating a bigger space in the cavity and that's sucking air in.

4.5.2.4 Conceptions about heat

Because of the overlap between heat and gas pressure, the conceptions which subjects held about the effect of heat on gases have already been discussed. However, the demonstration which involved inserting a heated metal ball through a ring provided insight into the subjects' understanding of the effect of heat on solids. All of the participants were familiar with the concept that heated metals expand although four could not provide an explanation as to why this happens. The others applied a molecular model to their explanations and some of these (4) were in keeping with the scientific view e.g., interview 1.

> S1: I think the flame heats up the ball and the molecules within are vibrating more vigorously and because they are vibrating I suppose it expands the actual metal ball.
> I: What about the size of the molecules themselves?
> S1: I don't think they'd change at all.

The remaining subjects (2) who referred to molecules did explain the phenomenon in terms of expansion of the actual molecules, rather than increased vibration.

During this demonstration two subjects clearly articulated world views of the effect of heating e.g., interview 10

> S10: I just assumed that the metal would expand because I knew our front door is wooden and when it gets hot it expands.

In this case the analogy proved helpful in explaining the target question, however, a second subject drew on an analogy from her own experience which was at odds with the scientific view, although she was able to recognise the conflict.

> S3: It's amazing how you can think of something and then you can think of a real world example and it doesn't work any more.
> I: What do you mean?
> S3: I just mean...OK you're heating it therefore its going to expand and I'm just like thinking well when you cook meat it kind of shrinks, it doesn't expand so...but I can't think of why the metal would shrink...I would have to say it will expand.
> I: Can you explain why?
> S3: The reason I thought it would expand was because you're heating it therefore once again whenever you heat something the molecules inside they gain the heat energy, they become more active, that's why I said the metal ball would expand because I thought that was going to happen. But then I thought of the meat and when you cook the meat and I can't explain why the meat shrinks.

Although this subject had a sufficiently developed molecular model to explain the expansion of a metal and this appeared to 'override' her own experience, the example illustrated how an everyday experience might impact on the learning of science by presenting the scientific view as counterintuitive.

4.5.2.5 Conceptions about physical and chemical change and the conservation of matter

Card 6, the burning candle, explored subjects' views about the nature of physical and chemical change, while card 8, the evaporation of acetone within a closed system, probed their understanding of the conservation of matter.

None of the subjects used the terms chemical and physical change to distinguish between the process of burning and melting nor did anyone attempt to apply a molecular model to their explanations. However, seven of the subjects were aware that they represented different types of processes, with the remainder (3) viewing them as the same.

Explaining the difference proved problematic for most subjects, but four were aware that melting was a readily reversible process while burning was not. This view, however, was generally associated with a belief that during burning matter disappeared e.g., interview 1.

> S1: I think there is a difference. Burning I assume would get rid of a substance and melting is just changing from one form to another.

Implicit in this is the belief that matter is not conserved during burning. One subject went further stating correctly that there would be less mass in the burnt candle but indicating that this mass had been converted to energy.

> S3: I see one as having less mass after being in this molten kind of state than the solid one.
> I: Where would that mass have gone if there has been a loss of mass.
> S3: Lost in energy.

Only one subject was able to provide a comprehensive and 'scientific' conceptual model to explain the event depicted in card 8.

> S7: There wouldn't be a change of mass when the acetone was heated or cooled. The acetone has changed form but the same amount of molecules are present all the time.

However, five of the subjects did not share this view, claiming that the vapour phase would have less mass than the liquid phase despite the fact that a closed system was depicted e.g., interview 3.

I: How would the mass of the tube be before heating and after heating?
S3: My first instincts are to say that would be more before heating because it's got the liquid form whereas in this one it's the gaseous form and gas is lighter than the liquid state.

A number of responses (4) similar to the one above indicated a lack of understanding of the concept of mass but also those of weight and density.

Subjects also provided a number of theories as to the fate of the acetone once it had been heated. These included the view that it had coated the inside of the glass, been absorbed by the rubber stopper or been absorbed by some entity between the air particles e.g., interview 10.

S10: Whatever is between the air particles might have absorbed the acetone, it may be something that can absorb things such as bad chemicals and pollution and that sort of thing, so maybe that's what's between the air particles.

4.5.3 Findings on subjects' post-instruction conceptions about changes in matter

As mentioned previously four subjects were interviewed on a second occasion, after they had received instruction on Kinetic Theory as part of their regular course. These subjects were selected because, in the initial interviews, they had all revealed a very poorly conceptualised particle model. It was thus of particular interest to see if this model had improved as a result of instruction. To this end subjects were presented with their individual CPIs and asked to comment on the statements they had made prior to instruction. A second profile was then produced for each subject on the basis of the post-instruction interview, and the two profiles were compared. Table 4.4 shows the pre- and post-instructional profiles for subject S10.

With one exception (S4 who, due to personal problems, had missed much of the course) all of the subjects had, after instruction, developed a molecular model of matter which incorporated the concepts of particles, energy and the interaction between these. However, it was noteworthy that, although they appeared to be more confident about using the scientific terminology, none of these subjects could apply this model consistently to explain changes in matter. This is best exemplified by their

Table 4.4.

The CPI for Subject S10 showing Pre and Post Conceptions about Changes in Matter.

Concepts	Pre-instruction conceptions	Post-instruction conceptions
Melting	'Something to do with particles joining together when they are frozen and losing their connection when they are water.'	'As the ice heats up they become less, the cohesive forces become less in the ice.'
Condensation	'It (condensation) comes out of the glass...the cold water in it perspires on the outside.'	'It (condensation) might have something to do with the ideas of atmospheric pressure like the difference between inside and outside.'
Evaporation	'The humidity picks up the water and then takes it up to the clouds.'	'The (water) particles heat up, they become more active, but then they must get so active that the air particles are able somehow to get them and they carry them into humidity.'
Evaporation	'Whatever is between the air particles might have absorbed the acetone'	'It's changed from being a liquid state to a gas state. It's not actually being absorbed by anything.'
Conservation	'The acetone is still in the test tube...the weight would be the same.'	'The acetone is still in the test tube...because the lids still on.'
Pressure	'The air that's inside the beaker will protect it (the paper) from the water.'	'It's pressure that keeps them (the water) out (of the inverted jar).'
Expansion	'Hot water would cause the air particles to heat up and would make them expand.'	'Particles don't expand as such they just jump around more.'
Expansion	'Heat causes the particles that make up the metal to expand.'	'They don't actually expand, they're in the same spot and they jump up and down more, so that they caused the ones...the particles next to them to move.'
Solubility	'The two separate entities mix together and one is stronger than the other so one dissolves the other.'	'The particles within the sugar grain are close and cohesive and then the water causes these cohesive forces to weaken and it then becomes adhesive to the water.'
Saturation	'They're (the sugar crystals) are not compatible to the water.'	'They've got strong cohesive forces and they haven't been there long enough so they're still not compatible to the water.'

post-instruction explanations of changes in state, which in general were now more in keeping with the scientific view e.g., subject S5 explaining evaporation.

Pre-instruction

> S5: Because they change their molecular structure then they get evaporated up into the atmosphere.

Post-instruction

> S5: They don't change their molecular structure. All the particles in the water sort of move around, but when they get heated up by the sun they move around quite a bit faster...then they rise and mix with the air particles.

However, the same subject was unable to use this model effectively to explain the reverse of this process, condensation.

Post-instruction

> S5: Well there are particles in the atmosphere all the time...so if you put a cold glass on a table the particles in the glass are quite fixed and rigid and the air particles with the water in it are moving so there must be some sort of force adhesive force between...oh no maybe not...because the cold air particles in the cold and the water particles in the air near the glass...I don't know.

Here the subject failed to give a complete explanation because she appeared to be unable to incorporate the idea of kinetic energy into her model, something which she had done when explaining evaporation. In fact the concept of condensation proved to be extremely difficult for all of the subjects to explain even after instruction e.g., subject S10 explaining condensation.

Post-instruction

> S10: It might have something to do with ideas of atmospheric pressure, like the difference between inside and outside.

Again there was no attempt by this subject to apply Kinetic Theory to her explanation despite having used it when describing melting and evaporation. In fact, in this instance, the subject appeared to demonstrate the phenomenon of chaining concepts, described by Vygotsky (1986), as she linked the concept of pressure to that of condensation, in an effort to provide an explanation.

In other cases conceptual change was only partial, with subjects incorporating the scientific view into their own pre-existing theory, or simply making peripheral changes to their theory on the basis of the new information e.g., subject S10 explaining evaporation.

Pre-instruction

S10: The humidity picks up the water and then takes it up to the clouds.

Post-instruction

S10: The (water) particles heat up, they become more active, but they must get so active that the air particles are somehow able to get them and they carry them into the humidity.

In this case the subject has persisted with her theory that water which evaporates is absorbed by atmospheric humidity, but has incorporated aspects of the scientific view of evaporation into this model.

However, there were a number of instances when all the subjects appeared to have undergone conceptual change. For example, prior to instruction each had believed that when matter was heated its molecules expanded. This view had been replaced by the scientific view that expansion of matter results from increased molecular vibration e.g., subject S5.

Pre-instruction

S5: I guess they (the molecules) must expand to fill up the balloon.

Post-instruction

S5: Molecules don't expand when they're heated, they move faster.

This was also true for the belief that matter could somehow vanish, a view held by two of the subjects, which was subsequently replaced by a conservative view of matter e.g., interview S10.

Pre-instruction

S10: Whatever is between the air particles might have absorbed the acetone.

Post-instruction

S10: It's changed from being a liquid state to a gas state. It's not actually been absorbed by anything.

4.6 Discussion

It was clear that, prior to instruction, many of the pre-service teachers who took part in this study held conceptions about matter similar to those recorded in the literature for children. Certainly their views on the thermal expansion of matter were very much akin to those described by Lee, Eichinger, Anderson, Berkheimer and Blakeslee (1993) for grade six students in the United States. Furthermore their views on the boiling of water were similar to those expressed by much younger school children in New Zealand (Osborne & Cosgrove, 1983). This was despite the fact that all but one subject had completed a science subject in Year 12 of high school.

It was particularly noteworthy that none of the subjects interviewed was able to apply Kinetic Theory with complete consistency when explaining a range of phenomena relating to changes in matter. Subject S3, who had successfully completed three science majors in Year 12 and possessed the most coherent molecular model, was unable to apply this model when attempting to explain changes in gaseous pressure, in this instance she reverted to a macro view. This lack of consistency was a common feature amongst many of the subjects who switched from micro to macro level explanation depending on the phenomenon to be explained.

Smith and Neale (1989) suggest that it may be useful to regard primary level teachers as adult novices, in some if not all, of the science areas they teach. According to Chi, Feltovich and Glaser (1981), novices tend to dwell on the surface structures of scientific problems (i.e., the objects referred to in the problems) with which they are confronted. This contrasts with experts who appear to look at the underlying scientific principles involved. The subjects in this study generally exhibited the characteristics of novices described by Chi et al. (1981), insofar as their initial response to the questions was to focus on the surface features presented. Certainly few applied the principles of Kinetic Theory to their explanations, even with considerable probing on the part of the interviewer.

There was also some evidence from the study to support the views of Strike and Posner (1992) and Yates, Bessman, Dunne, Jerston, Sly and Wendelboe (1988) that alternative conceptions are often not clearly articulated in advance of instruction, but are generated spontaneously. Certainly a number of the subjects interviewed in this study clearly articulated that they had never previously thought about the everyday phenomena they were being asked to explain, yet they generally proceeded to produce a conception in an attempt to provide a solution.

The interviews conducted after the course of instruction revealed that while some conceptual change had taken place, this was generally partial with new ideas being incorporated into existing theories rather than replacing them. This is perhaps not surprising in light of Chinn and Brewer's (1993) assertion that individuals often reinterpret anomalous data and make peripheral changes to their existing theories. Having said this, the degree of conceptual change which had taken place appeared to vary more between concepts than between individuals. As mentioned previously, certain alternative concepts, such as the belief that molecules undergo expansion seemed to change quite readily, while alternative views on condensation appeared to be much more resistant. In one instance, the pre-instruction view was replaced by a post-instruction view, which, although quite different, was equally at odds with scientific thinking.

The findings of this very limited pilot study appear to reaffirm the beliefs held by researchers such as Gunstone and Northfield (1994), who contend that conceptual change rarely involves the complete abandonment of one notion in favour of another but rather, as suggested by Summers and Kruger (1994), it is often partial and messy.

Nevertheless, there were indications even from this small study that within the broader topic of changes in matter, some alternative concepts were more resistant than others. Thus, as advocated by Driver, Leach, Scott, and Wood-Robinson (1994), it was decided to devote more time to these during the course of instruction in the main research study.

4.7 Summary

The pilot study, described in this chapter, established that the data collection and analysis procedures were effective as they produced findings consistent with those reported in the literature for similar groups. These procedures also proved to be of sufficient sensitivity that they could be employed to detect qualitative changes in students' conceptions after a period of instruction. This was an important consideration for the main study in which it was hoped to record conceptual changes in students' thinking not only quantitatively, but also by employing qualitative methods.

Furthermore, the pilot study allowed the researcher to establish that he had the necessary skills to employ IAI and POE techniques and to resolve some of the minor problems related to these forms of data collection, such as the limitations of written responses to the POE probes, before embarking upon the main study.

The chapter which follows describes the strategies employed during the teaching intervention undertaken in Fiji.

Chapter 5

The Teaching Intervention

5.1 Introduction

This chapter describes the teaching intervention and justifies the use of the various teaching strategies employed with the experimental group. In effect this is an extension of the methodology. However, because of the significance of the teaching intervention in this study, together with the fact that it was conceptualised and implemented in Fiji, it has been presented as a separate chapter.

The context for this chapter is provided by the final two objectives of the study which were:

1. To design and implement an intervention, which would be informed by a constructivist view of learning, to improve conceptual understanding.

2. To evaluate the impact of the intervention and, in particular, its comparative effectiveness with the two major ethnic groups within the student population of the college, namely the ethnic Indians and the indigenous Fijians.

5.2 Instructional Strategies

The teaching intervention began in the second week of the second semester, and lasted for six weeks (the normal amount of time allocated for the intended topics). This represented a total contact time of 18 hours with each of the control and experimental groups. The aim of the instruction for both groups was to teach the scientific concepts relating to matter and how it changes, using the following sequence of topics with each group: *states of matter; solubility; chemical and physical change; heat; and pressure.* However very different teaching approaches were used in the case of the control group and the experimental group. These are outlined below.

5.2.1 Control Strategy

The control strategy duplicated the teaching procedure normally employed by the college science education lecturers in delivering the unit entitled Curriculum Studies in Science (CSS II), which is intended to prepare the students to teach the

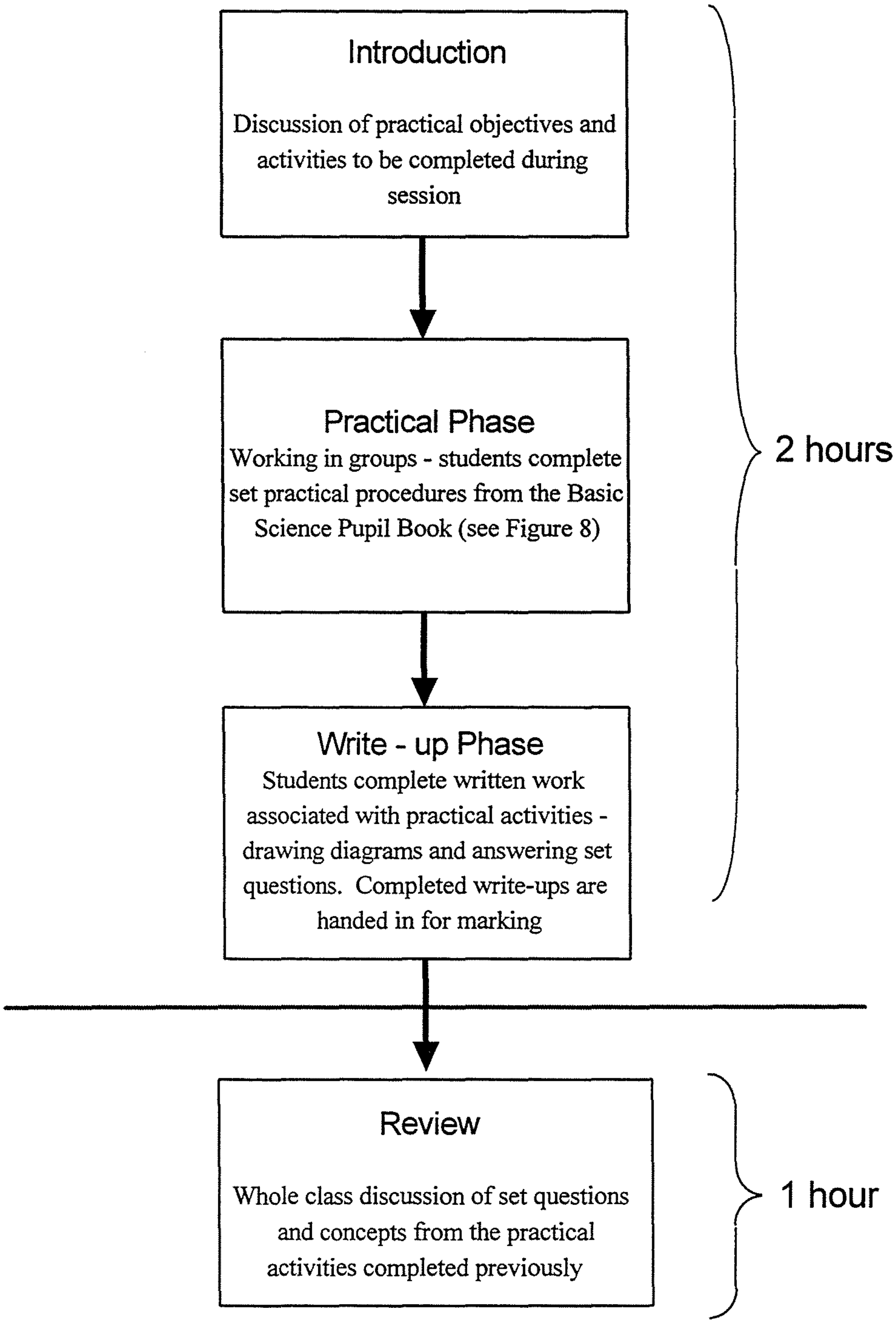


Figure 5.1. A flow chart of the sequence of a typical weekly control session comprising a two hour (double) followed by one hour (single) class.

Basic Science course covered at the upper primary level in Fiji (see Figure 5.1). This is made clear in the aim set out for the course which reads as follows:

> To enable students to develop skills, knowledge and attitudes to be able to teach Basic Science to Class 7-8 pupils. (Fiji Ministry of Education, 1992 p53).

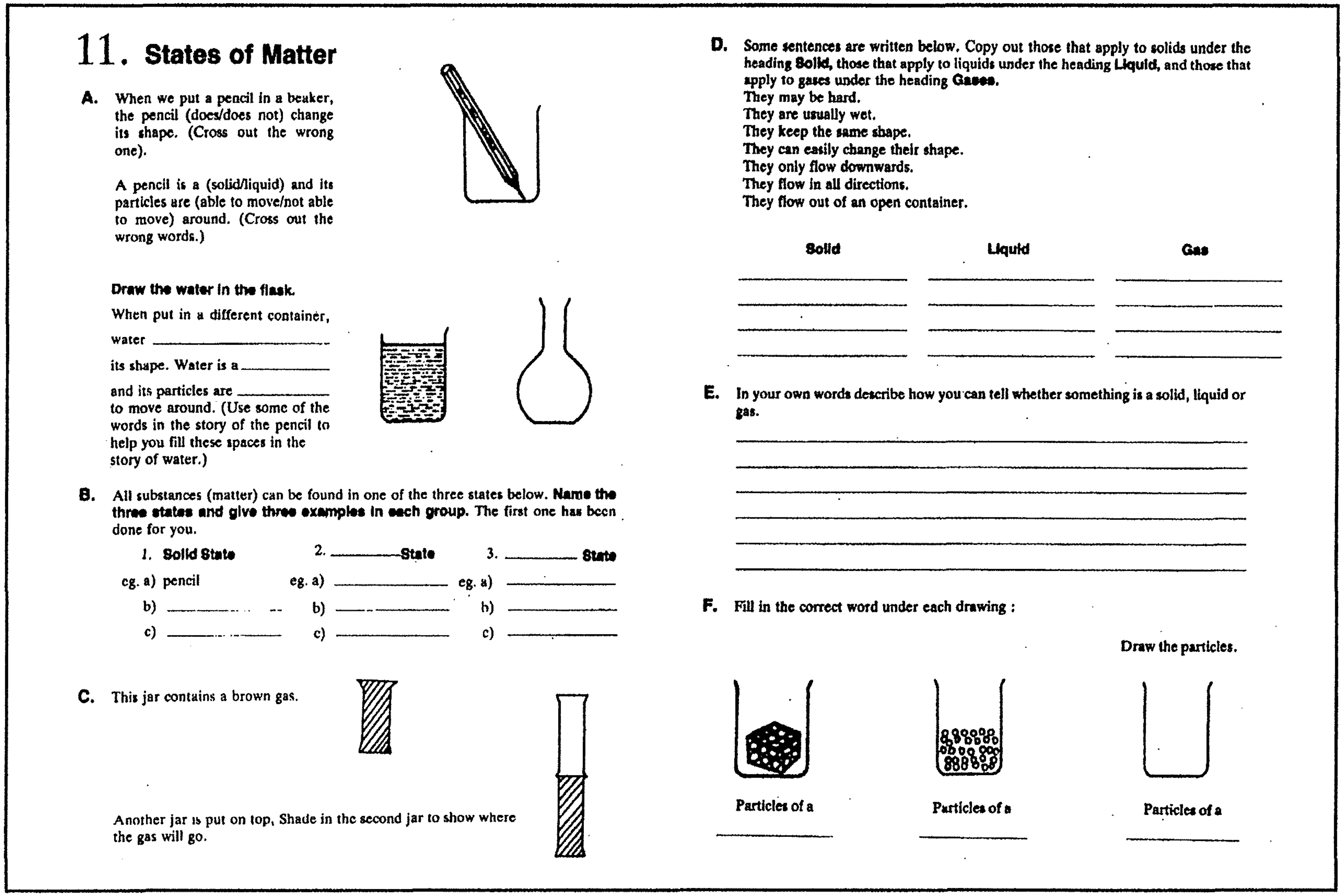
A complete list of Basic Science course objectives for the topics of states of matter; solubility; chemical and physical change; heat and pressure is provided in Appendix B.

This strategy involved strict adherence to the activities presented in the teacher's guides and pupil books used for teaching Basic Science to Years 7 and 8. In any given double lecture session the students were required to complete three lessons on a common theme from the pupil book (see Figure 5.2).

The students worked through the highly structured activities in the Basic Science pupil book as if they were themselves upper primary pupils. The practical activities were conducted in groups of three or four students, not essentially for educational reasons, but because of the need to share books and equipment, and the activities were written up and handed in to the lecturer for marking at the end of the session.

During the one hour single lecture which followed later in the week, the practical write-ups were returned to the students and activities and set questions discussed. At this stage difficult concepts which arose from the discussions were explained to the group by the lecturer. This was usually by means of a verbal and/or blackboard presentation.

Both the control and experimental sessions were conducted by the researcher throughout the intervention. The researcher had previously taught an environmental studies elective in the first semester, and this had assisted in his acceptance into the college community. However, a number of measures were taken to ensure that the teaching with the control group was in keeping with the instructional practices used by the normal lecturer. Thus, prior to the intervention, the researcher observed the lecturer taking classes for one week. Then, at the beginning of the intervention, team teaching involving the lecturer and researcher was employed for the first session.



11. States of Matter

A. When we put a pencil in a beaker, the pencil (does/does not) change its shape. (Cross out the wrong one).

A pencil is a (solid/liquid) and its particles are (able to move/not able to move) around. (Cross out the wrong words.)

Draw the water in the flask.

When put in a different container, water ____________ its shape. Water is a ____________ and its particles are ____________ to move around. (Use some of the words in the story of the pencil to help you fill these spaces in the story of water.)

B. All substances (matter) can be found in one of the three states below. **Name the three states and give three examples in each group.** The first one has been done for you.

1. **Solid State**	2. ________ **State**	3. ________ **State**
eg. a) pencil	eg. a) ________	eg. a) ________
b) ________	b) ________	b) ________
c) ________	c) ________	c) ________

C. This jar contains a brown gas.

Another jar is put on top. Shade in the second jar to show where the gas will go.

D. Some sentences are written below. Copy out those that apply to solids under the heading **Solid**, those that apply to liquids under the heading **Liquid**, and those that apply to gases under the heading **Gases**.

They may be hard.
They are usually wet.
They keep the same shape.
They can easily change their shape.
They only flow downwards.
They flow in all directions.
They flow out of an open container.

Solid	**Liquid**	**Gas**

E. In your own words describe how you can tell whether something is a solid, liquid or gas.

F. Fill in the correct word under each drawing :

Draw the particles.

Particles of a ____________ Particles of a ____________ Particles of a ____________

Figure 5.2. An example of a lesson on matter, taken from the Basic Science Pupil Workbook for Class 7 (Fiji Ministry of Education, 1982).

After this the researcher took over the teaching with the lecturer acting as an observer and critic.

5.2.2 Experimental Strategy

5.2.2.1 Rationale

Some of the teaching strategies employed with the experimental group should be viewed in the context of the researcher's earlier statement that he had been influenced by the social constructivist perspective espoused by such authors as Vygotsky (1962) and Solomon (1987). Certainly these authors claimed that the social context can make an essential difference to the learning process and advocated taking advantage of the social nature of learning to foster knowledge. Fellows (1994) also points to the social construction of knowledge and claims that the brain is a social intellect and as such has an innate drive to belong to a group and relate to others. Furthermore, she argues that students need to work in friendly groups where they feel relaxed, yet alert and supported. In citing Cohen (1984), Fellows states that learning increases when students interact by jointly solving problems as there seems to be a positive and critical link between verbal interaction and learning. Thus talking in groups provides students with opportunities for processing experiences and reflecting on their understanding. Students rehearse their explanations and reconstruct their knowledge as they engage in discussion with others.

Clearly the construction of knowledge can never be an entirely social activity, because, as Solomon (1987) points out, we should not assume that the social influences rule at the expense of personal reflection as, in the last analysis, what we construct is our own picture of the world and its phenomena. Having said this, if the learning environment is appropriate to the needs of the students, the final process of personal construction should be facilitated.

This view of learning as a largely social activity appeared to be a fitting construct for the South Pacific environment, where as previously mentioned, amongst the Fijians there is a strong oral tradition and, in general, social interaction still tends to be co-operative rather than competitive in nature, despite considerable Western influence. Given this cultural background there appeared to be a likelihood that Fijian students would possess the necessary social skills to embrace teaching strategies such as collaborative group work which are in accord with the social constructivist perspective. These strategies only succeed when students are effective in communicating their ideas and able to help the other group members see why their idea contributes to the group goal (Linn & Burbules, 1993).

In advocating collaborative learning strategies, the researcher was also able to draw on his own experience of conducting in-service science workshops with primary teachers in Fiji and elsewhere in the Pacific. Collaborative group work had been employed in these and had proved to be well received and an effective forum for generating discussion and sharing ideas. A number of teachers commented that during their own school days they had little opportunity to work collaboratively in groups because of the highly competitive and individualist nature of the classroom environment in many Fiji schools. This form of environment is largely a hangover from colonial times, but has been perpetuated by the growth of a very extreme examination culture which puts enormous pressure on teachers in Fiji to achieve high pass rates. Faced with such a situation, most teachers perceive a rote learning approach as the most risk-free strategy to adopt. The researcher's own observations of a number of primary science classes tended to confirm this assertion (Taylor & Macpherson, 1992b).

In addition to the theoretical and experiential influences mentioned above, the design and content of the teaching intervention drew upon the pragmatic approach to science education for primary teachers used by Summers and Kruger (1994) in developing the PSTS materials. These authors argued that in-service training, if well designed and based upon a current consensus of what constitutes good practice, can substantially improve primary teachers' understanding of science concepts. Thus, in developing in-service materials, they employed considerable use of analogies in an attempt to build on teachers' existing ideas. They also attempted to encourage active, collaborative learning in which views were expressed, exchanged and developed through discussion and social interaction, while at the appropriate time they confronted teachers with the currently accepted scientific view of a particular concept (Summers, 1992). This approach they claimed had yielded considerable success in improving the conceptual understanding of UK primary teachers in a number of different areas of science, even though many of those teachers involved in the training programs claimed to have a weak content knowledge of science and lacked confidence in their ability to teach it.

The researcher drew on a number of the teaching techniques recommended by Kruger and Summers, in particular the use of analogies. This appeared to be a strategy which would transfer readily to the Fiji context, and was in keeping with the researcher's view that an approach to conceptual change which built on teachers' existing ideas by relating abstract scientific concepts to their own everyday experience (i.e., a continuous approach) might be more suitable than the constant use of cognitive conflict (discontinuous approach) which risked undermining the confidence of those student teachers whose preconceptions were continually shown to be 'wrong.'

5.2.2.2 Background and justification of the teaching methods employed with the experimental group

The above section outlined some of the rationale behind the global approach to instruction adopted with the experimental group. The individual strategies which contributed to that approach were selected on the basis of their reported effectiveness in the literature coupled with the researcher's experience of working in Fiji, and his sense of which strategies would be appropriate and feasible to use in that context. The section which follows examines the individual teaching strategies chosen, and provides justification for this choice based on evidence of their effectiveness in improving students' understanding of both science and how learning takes place.

Providing the learners with an explicit introduction to constructivism

This approach has been advocated by Summers (1992) who, while recognising the risks involved in introducing teachers to a complex model, felt that the potential metacognitive value of this strategy justified it. During their in-service work with primary school teachers, Summers and his co-workers provided the participants with a handout which explained, in simple terms, a constructivist model for learning science (in this instance force), involving the following introduction and steps:

> A constructivist model of learning about force:
>
> It is a basic principle of the approach to learning which underpins this course that, for an understanding of force to be developed, it is necessary for both teacher and learner to:
> (1) first become aware of the ideas about force which the learner already possesses.
> Instruction then consists, not of adding on new bits of knowledge to this prior knowledge, but of facilitating development of the learner's existing ideas.
> This development may involve:
> (a) the changing of existing views,
> (b) the discarding of them in favour of new views, or
> (c) the acceptance of new views which co-exist with the previously held views but are applied only in a science context.
>
> This development of ideas is facilitated by:
> (2) providing experiences and discussions which cause the learner to consider any inadequacies in his or her existing views and to become dissatisfied with them.
> (3) providing experiences and discussion which cause the learner to generate a new view by constructing an idea or explanation which is more satisfactory and makes better sense of the experiences.
> (4) moving the learner, as he/she engages in the process of constructing new knowledge, towards the scientific view by presenting the latter in such a way that:
> (a) it can be understood,
> (b) it is believable,
> (c) it is seen to apply consistently in a wide range of situations,
> (d) it seems to be useful for the solving of problems,
> (e) it is able to explain situations more satisfactorily than previously held views
> (Kruger, Palacio and Summers, 1991 p. 39)

Summers and Kruger (1994) felt that this introduction to a constructivist view of learning assisted metacognitive development as it helped the participants to gain a better understanding of their own learning process. This was especially so as they became aware of conflict in their views, or of the partial nature of their understanding. Teachers developed a heightened awareness of their intuitive views and those of children and eventually came to recognise that many intuitive feelings were scientifically wrong. They also acknowledged that a scientific explanation did exist for the various phenomena they encountered, even if they could not supply it or perhaps still felt more attracted to their original view.

The teachers were also provided with a diagrammatic representation of this model which is shown below:

This model for learning of scientific ideas can be summarised thus:

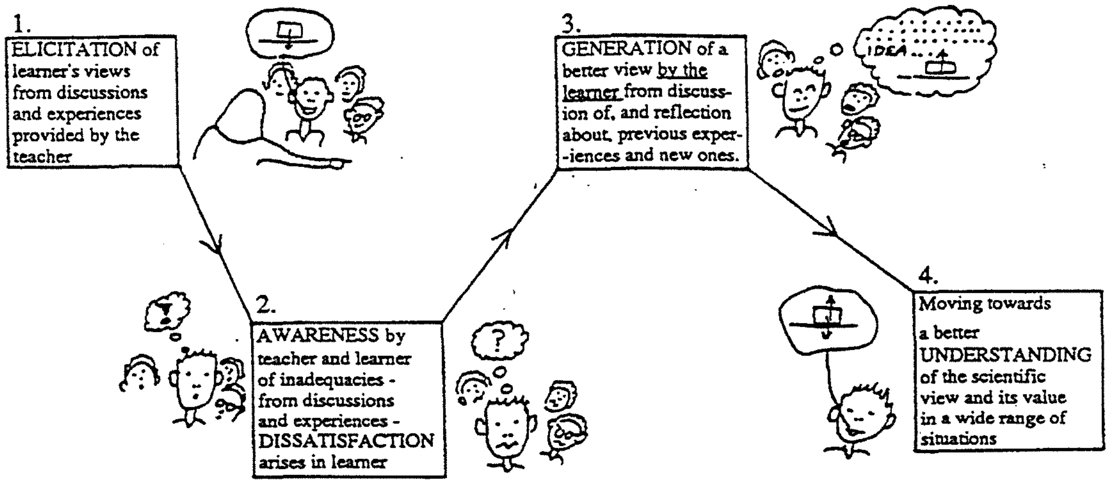


Figure 5.3. A diagrammatic representation of a constructivist model of learning (Kruger et al., 1991 p. 40).

Elicitation and discussion of prior conceptions about Kinetic Theory and matter

As mentioned in chapter 2, one of the fundamental principles underlying a constructivist model of instruction is the importance of acknowledging the learner's existing ideas (e.g., Driver, 1989; Summers, 1992). This has also been recognised by researchers working in the context of developing countries (e.g., Jegede & Okebukola, 1991b). Millar (1988) states that, in his view, the best available concept learning model for designing in-service courses in physical science for non-specialist teachers is the constructivist model. This recognises that non-specialist teachers already hold some ideas about most physical science concepts in the syllabuses, though these ideas may well differ from the accepted ones. Thus, if courses are to succeed, they need to take account of these prior ideas. For each topic, a starting point is to elicit teachers' current ideas and understandings on the topic. On the basis of this, they can then be directed to carefully chosen readings and practical activities, designed specifically to challenge or deepen existing ideas.

The use of analogies and models

The theoretical background to the use of analogies has already be discussed in some detail in chapter 2. As mentioned in that section, this approach offers considerable promise for building on learners' existing ideas and linking abstract concepts to phenomena which are familiar to the learner. It has also been used with purported success in the training of primary level teachers in science and specifically the topic of 'matter.' Pendlington, Palacio and Summers (1993) in the UK and Rollnick (1988) in Africa have employed analogical models to convey the conception that all apparently continuous matter is composed of discrete particles. For example, Rollnick attempted this by asking students to look closely at an apparently continuous piece of cloth, while Pendlington et al. used among others, the analogy of a beach being composed of tiny particles of sand.

As mentioned previously, Champagne, Gunstone and Klopfer (1985a) caution that the uncritical use of analogies can generate alternative conceptions. However, Treagust, Harrison, Venville and Dagher (1996) point out that research has shown that the effectiveness of analogical instruction can be improved by training students in analogical reasoning. Furthermore, they contend that when a competent teacher presents analogies systematically, the resultant student understanding is compatible with that of the teacher's expectations.

Noh and Scharmann (1997) have also demonstrated that the use of high quality pictorial materials at a molecular level helped Korean students construct more scientifically correct concepts of certain aspects of chemistry when compared to a more traditional approach. This was particularly true for new or difficult concepts.

Using laboratory activities in collaborative learning settings.

Much has been written about the value of group work in science education. According to Hatano and Inagaki (1987) working in groups seems to support the construction of individual knowledge of the members. This is particularly true when students are required to explain or defend their viewpoints, as they are more likely to construct a deeper understanding because they have to evaluate, integrate, and elaborate their existing knowledge. In addition, the social setting makes the enterprise of comprehension more meaningful. Linn and Burbules (1993) also state that most arguments for group learning are usually buttressed by the claim that students learning together co-construct more powerful understandings than they could construct alone.

According to Johnson, Johnson and Holubec (1993), when students are required to compete with each other for grades, they work against each other to achieve a goal that only one or a few students can attain. There is thus a negative interdependence among students as they perceive that they can only obtain their goals if the other students in the class fail to obtain their goals. However, in co-operative learning situations there is a positive interdependence among students' goal attainments, as students perceive that they can reach their learning goals only if the other students in the learning group also reach their goals. A recent meta-analysis of 46 studies on co-operative and competitive efforts on problem solving by Qin, Johnson and Johnson (1995) indicated that co-operative efforts resulted in better problem solving than did competitive efforts. According to Collins, Brown and Newman (1989) this may be because learning through co-operative problem solving gives rise synergistically to insights and solutions that would not occur in a competitive situation, as group learning is a powerful mechanism for extending the learning resources both in cognitive and affective terms. Roth and Roychoudhury (1993) believe that the affective benefits may arise particularly with pre-service and in-service primary teachers as collaborative grouping is a widespread instructional method with children at the primary level. Although this statement was probably made with a Western context in mind, some primary teachers in Fiji do use group working arrangements with their classes from time to time (Taylor & Macpherson, 1992b).

Kempa and Ayob (1995), conducting research into group work outside a Western context, have demonstrated that a significant amount of 'learning from others' occurred amongst Malaysian students undertaking group problem-solving tasks in science. Of particular interest in this study was a finding which indicated that even students who appeared to participate little in the tasks provided still benefited in terms of their achievement as a result of the group activity.

Much of what is written about group learning in science presents it as an apparent panacea. However, Linn and Burbules (1993) caution that advocacy of group learning as a mechanism for knowledge construction oversimplifies important issues concerning the social structure of groups, the goal of individuals in groups, and the diverse nature of knowledge construction, and in fact there is much disagreement about how and when group learning fosters effective knowledge. Furthermore, as Johnson and Johnson (1995) point out, simply placing students in groups and telling them to work together does not mean that they know how to co-operate or that they will do so even if they know. Some students will defer to the high-ability members who may take over the important leadership roles in ways that benefit them at the expense of other group members. Similarly, other students will be inclined to leave the work to others while they exercise token commitment to the task (Johnson & Johnson, 1990). According to Blumenfeld, Marx, Soloway and Krajcik (1996), effective group work requires students to share ideas, take risks, disagree with and listen to others, and generate and reconcile points of view. These norms, they claim, do not necessarily pervade classrooms.

Moreover, although groups can draw on the knowledge of all participants to locate ideas that help construct knowledge, success depends on the knowledge available. If the group lacks sufficient information, this process will fail (Linn & Burbules, 1993). Webb and Cullian (1983) have also found that when groups are of uniform ability there is much less interaction and explanation between individuals than when they are of mixed ability. Having said this Salomon and Globerson (1989) caution that the perceived high ability of some group members can create 'status sensitivity' in some groups, with the higher status members sometimes dominating the group and controlling outcomes. This effect tends to be more likely as group size increases.

However, Gillies and Ashman (1994) believe that the teacher or instructor can do much to overcome these potential problems by careful monitoring of the class-wide situation during group activities. This, they claim, can be achieved by providing specific feedback on each group's progress towards its goal and communicating clear expectations of the purpose of group processes. Thus, by acting as a facilitator of learning and offering guidance and assistance, answering students' questions and encouraging them to reflect on their own learning processes, the teacher can support or 'scaffold' the construction of group understanding (Rosenshine & Meister, 1992).

The use of concept mapping techniques

A number of authors have demonstrated the positive effects of the use of concept mapping, as described by Novak and Gowin (1984), during science instruction. Roth and Roychoudury (1993) found that the use of concept maps helped Canadian pre-service and in-service primary teachers to construct scientific knowledge and develop favourable attitudes to meaningful learning in science. In the UK, Pendlington et al. (1993) have also recommended the use of concept maps in the in-service training of primary level teachers, while Adamczyk and Wilson (1996) claim to have used the technique of concept mapping successfully to diagnose practising science teachers' misconceptions in physics, and subsequently evaluate the effects of in-service training activities on their knowledge and understanding.

Other studies conducted in non-Western countries (e.g., Jegede, Alaiyemola & Okebukola, 1990; Okebukola & Jegede, 1988 (in Nigeria); Kei & Mee, 1991 (in Malaysia)), have demonstrated significantly better achievement on science tests with experimental groups of students who used concept mapping as part of their instruction, as opposed to control groups who did not. Interestingly, Jegede et al. (1990) also found that the use of concept maps during instruction reduced students' anxiety towards the learning of science. Furthermore, Okebukola and Jegede (1988) noted that students working together on concept-mapping tasks attained meaningful learning better than students working individually.

This section has provided justification for the selection of the particular teaching approaches that were used with the experimental group in the intervention. The next section describes how these approaches were implemented in that context.

5.2.2.3 Implementation of the experimental treatment

The experimental group studied the same substantive content as the control group, although the Basic Science Teacher's Guide and Pupil Book were not used in class. All of the constructivist strategies discussed in the previous section were employed at various stages during instruction in an attempt to improve the students' conceptual understanding of Kinetic Theory and how this can be applied to the behaviour of matter. Prior to the intervention, each strategy was discussed with the students in order to obtain their views on its suitability. As a result of this negotiation, one strategy, to be discussed later (page 171), was not employed. The elicitation and prevalence phases of the project had revealed those concepts relating to matter and how it changes which were poorly understood, and most emphasis was given to these. The manner in which the various strategies were employed during the teaching intervention is described below.

Introducing constructivism

As it was the intention to employ teaching techniques based on constructivism throughout the intervention, it seemed appropriate that the students be explicitly introduced to a constructivist model for learning science as advocated by Summers (1992). This was particularly true as none of the students or the lecturers in science education were familiar with the term constructivism or any of the theories associated with it.

Thus in an effort to encourage the student teachers to reflect on their own learning, they were presented with a constructivist model for learning science. It was considered that the model used by Kruger et al. (1991) might be too complex for the student teachers in Fiji, and instead a simpler model was developed from an explanation of a constructivist view of learning provided by Bell (1993). This read as follows:

> Children have their own ideas about things which happen in the world. They get these ideas from other people or from their own personal experience. Often the children's ideas are different from the ideas which scientists have. So when they come to school learning about science is not a matter of filling their empty heads with new scientific ideas, but about changing the ideas they already have. So

learning is a question of changing children's existing ideas rather than the children simply absorbing and accepting new ones. This view of learning is called the 'constructivist view of learning' because children often have to construct or build new ideas about the world during science lessons. (adapted from Bell, 1993 p. 23)

The students were also provided with a diagrammatic representation of this model based on that produced by Kruger et al. (1991), but again this was simplified to make it more appropriate to the Fiji context (see Figure 5.4).

Introducing the idea of constructivism required considerable sensitivity as there was a risk that such a strategy could easily alienate student teachers who found a constructivist model difficult to comprehend. However, during the discussion of constructivism, the students were able to identify elements of children's thinking which were different from the scientific view and which they had come across themselves. Consequently, the introduction of ideas relating to constructivism did not appear to alienate or cause concern amongst the students.

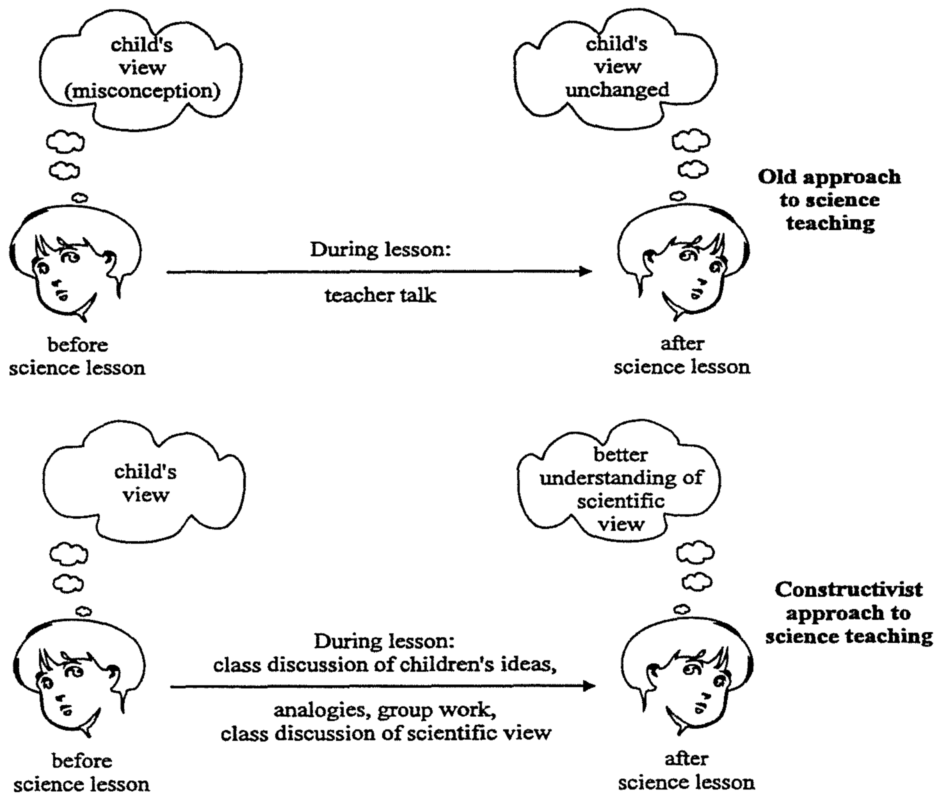


Figure 5.4. The simplified diagram of a constructivist view of learning presented to trainee teachers in Fiji.

The introduction to constructivism was presented to the experimental group just prior to the semester break, and was reiterated when they returned at the start of the first session of the intervention.

Eliciting prior conceptions

As it was important for the students to become aware of their own ideas about matter, some time was spent eliciting and discussing students' views at the beginning of each new topic, before proceeding with instruction. Since this was a relatively unfamiliar experience for most of the student teachers, and many seemed initially reluctant to expose their potential lack of knowledge in a whole class forum, in the first two weeks they were provided with examples of alternative conceptions about matter derived from the pilot study, described in chapter 4, which was conducted with an equivalent group of students in Australia. This allowed the Fiji students to become familiar with the strategy of discussing pre-existing ideas without the threat of exposing their own lack of understanding This approach had been recommended by Osborne, Biddulph, Freyberg, and Symington (1982), and when utilised in the Fiji context, appeared to reassure the students, who had clearly not anticipated that Western students would hold such alternative conceptions. As the intervention proceeded the students become more comfortable with the practice of answering questions prior to instruction, and it was no longer necessary to provide alternative conceptions from an external source.

Using analogies and models

Throughout the teaching intervention in Fiji, extensive use was made of analogies in an attempt to link the target conceptions to students' existing conceptions. These analogies took two forms. A few were carried out as practical activities such as the analogy used by Stavy (1991) in which iodine evaporation served as an analogous example for the evaporation of acetone. However, much greater use was made of diagrammatic analogies. These were largely taken from the work of Pendlington et al. (1993). An example of one such analogy is shown in Figure 5.5.

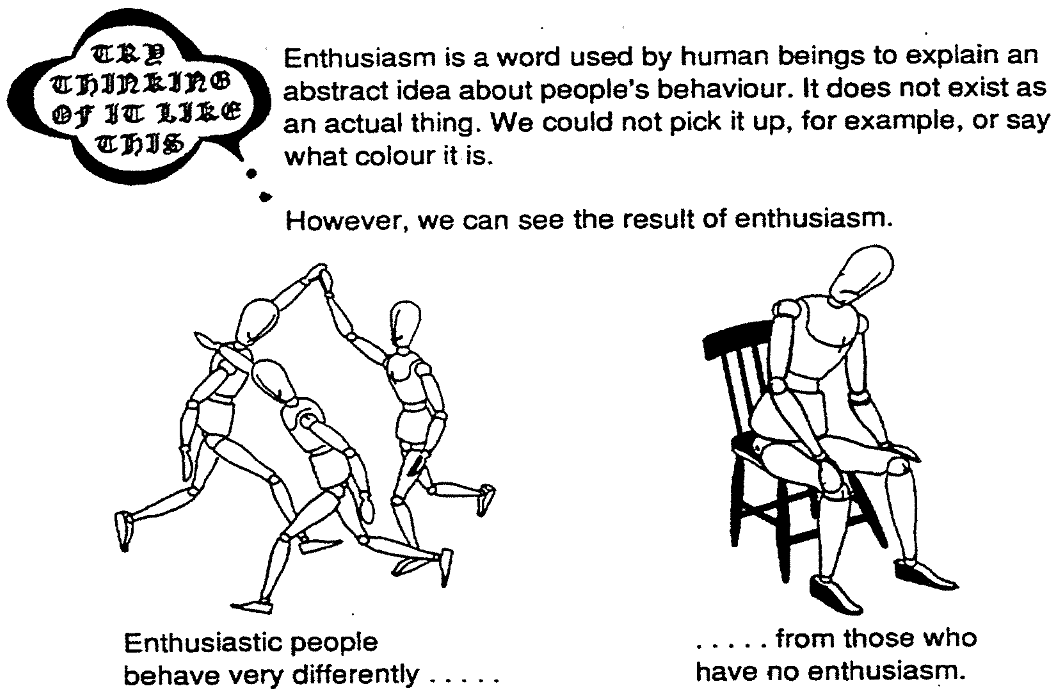


Figure 5.5. An example of an analogy used in the interventions which presents enthusiasm as analogous to energy (Pendlington et al., 1993).

The diagrammatic analogies were frequently used in the initial class discussion in an attempt to assist the students to develop the necessary concepts which would allow them to work on the problems presented later in the session.

Similar use was made of models, in particular a commercially produced Kinetic Theory model consisting of a clear plastic tube which housed a number of small beads. Vibrations were produced by a battery operated piston which agitated the beads to varying degrees thus simulating matter in various states. A plunger was used to reduce the vessel's volume when discussing concepts related to gaseous pressure (Figure 5.6).

This model provided the students with a strong visual representation of how particles behaved in different conditions. The students were shown how to construct a low cost version of this model which they could use for themselves throughout the intervention. Other models, such as the 'cannonball model' which helps students to visualise the transfer of energy between particles, were also constructed by the students (Figure 5.7).

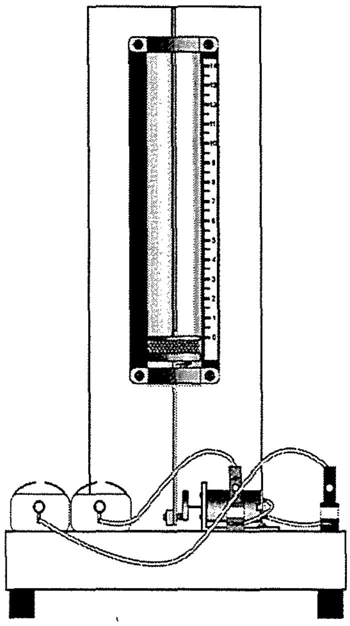


Figure 5.6. A diagrammatic representation of the commercially produced Kinetic Theory model used with the experimental group.

As with the introduction to constructivism, and in keeping with the views of Treagust et al. (1996) that analogical reasoning improves with training, the students were given some prior instruction in the use of analogies and their potential effectiveness in science teaching. During this session, the cloth and beach analogies, cited in the previous section, were used as exemplars of how to convey the concept of the particulate nature of matter.

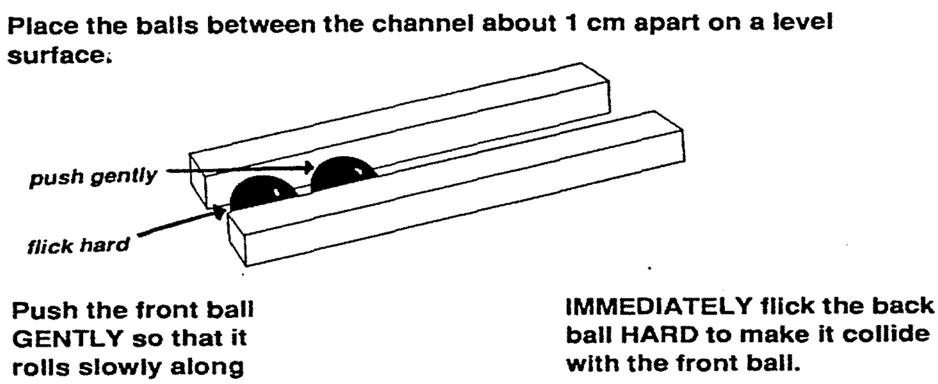


Figure 5.7. The cannonball model used to demonstrate energy transfer between particles (Pendlington et al., 1993).

Using collaborative group work

Despite the potential problems of group work mentioned in the previous section, the strategy of exploring simple science problems in small groups was used with the experimental group of pre-service teachers in Fiji. The groups were limited to three or four but students were allowed to choose their own partners. These groups were generally of mixed ability in terms of the science backgrounds of the students. In order to ensure that the students had sufficient background knowledge to work on the problems presented, the necessary key concepts were discussed with the whole class before group work commenced. During the group work sessions the students carried out a series of activities and attempted to negotiate explanations of various phenomena which were later shared in a whole class discussion.

At this point it is appropriate to clarify the terminology used here. The activities were undertaken in a collaborative group work setting insofar as the students jointly worked out a single solution to each problem. This is somewhat different from a co-operative setting which involves dividing a task into parts and having each group member complete one of the parts. This distinction is not always made clear in the literature even though it is an important one because, of the two approaches, collaborative learning requires greater social skills (Linn & Burbules, 1993).

Concept mapping

This technique was also used with the experimental group in the intervention. At the beginning of the intervention, the students were given instruction in how to construct concept maps. They were then asked to construct concept maps relating to changes in matter prior to the first teaching session. This exercise was repeated towards the middle of the intervention. The work was carried out collaboratively in accordance with the suggestion of Okebukola and Jegede (1988). The initial maps were returned to the students after the second mapping session to allow for comparison and discussion of changes which had taken place. It had been intended to carry out a final mapping session at the very end of the intervention, but time did not permit this.

One other strategy, that of reflective journal writing, was also considered for possible use with the experimental group, as one of its intended aims is to engage students in thinking more deeply about the science concepts their practical activities were intended to illustrate (Christensen, 1995). This may also have provided some useful insights into how the students felt about the various activities in which they were engaged. However, students in Fiji are used to a very formal style of writing in science, thus it was likely that considerable practice would be required before they would be confident using an informal style of writing. In fact, when this possible approach was discussed with the group prior to the intervention, a number of students expressed a desire to continue using the more formal style with which they felt comfortable. These views, plus that of the researcher that the group was already being exposed to sufficient new ideas meant that this approach was not included in the intervention.

Although it was not the intention to employ excessive cognitive conflict throughout the teaching experiment, it was impossible to avoid this strategy entirely, and in a few cases practical activities were presented in which the outcome clearly conflicted with the views of most of the students. In such instances the scientific view was not presented as superior to the students' original conceptions but as an appropriate view to use in the science context. The aim was to encourage students to achieve a better understanding of the scientific view rather than necessarily attempting to extinguish the old view.

5.2.2.4 The sequence of instruction with the experimental group

Figure 5.8 shows the sequence of strategies typically employed in presenting a particular topic to the experimental group. Each topic would normally be covered in one week. The sequence was designed to expose the students to a constructivist learning environment in which there was ample opportunity for discussion and negotiation of ideas and where the lecturer acted as a facilitator of learning rather than simply a provider of factual information. The intention was that the strategies would complement each other in a way which helped the students build a better understanding of each topic. As such, each new topic began with a class discussion in which the students were initially asked questions to elicit their prior conceptions. This revealed some of the students' alternative conceptions and uncertainties. This led to further discussion involving the presentation of analogies, models and occasionally demonstrations in order to provide the students with new information which would help them construct a new view closer to that presented by science. The information drawn out of this discussion also provided key concepts necessary to work on the problems presented to the students in groups. Once in the group format, the students conducted three or four practical activities and were asked to develop a theory to explain the outcome of each activity. The lecturer acted as a facilitator throughout these activities, answering questions and providing input where knowledge was lacking or concepts had not been fully understood. Some of the theories developed were then presented to the whole class as part of the summary discussion. This also involved revisiting the models and analogies in order to help clarify various points. During the summary sessions the lecturer monitored the discussion carefully for any indications of improved understanding or conceptual change amongst the students.

In the single one hour session which followed, the students were provided with handouts on the topic which contained the 'scientific view' of various phenomena which were discussed further in a whole class forum. While there was a risk that some students might perceive rote memorisation of the 'scientific view' as *the* learning task, the questions and discussion were used to gauge students' comprehension and ensure, as far as possible, that students took away an understanding of the concepts which underpinned this view.

This teaching sequence was considered to be consistent with the constructivist model of learning outlined by Kruger et al. (1991).

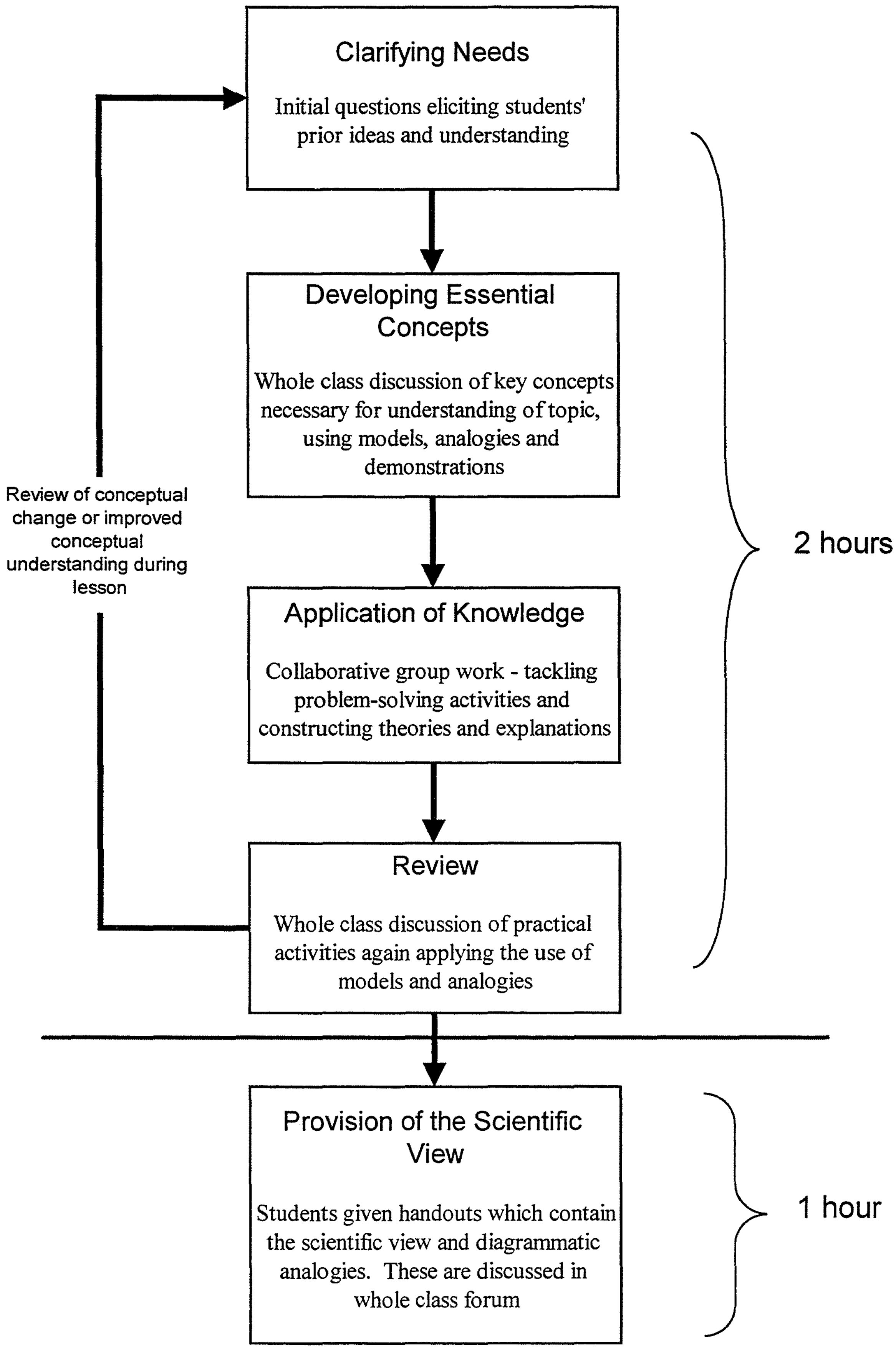


Figure 5.8. A flow chart of the sequence of a typical weekly experimental session comprising a two hour (double) followed by a one hour (single) class.

The following teaching steps taken from an actual lesson on gas pressure illustrate this approach further.

Step 1 - Clarifying needs

Students discussed a series of questions intended to elicit their views on what causes gaseous pressure and what could produce changes in the pressure of a gas in a sealed syringe.

Step 2 - Developing essential concepts

The analogy shown in Figure 5.9 was introduced and discussed to help develop the concept of pressure resulting from the impact of gas particles. The Kinetic Theory model was then employed to help illustrate how changing volume and temperature could affect the behaviour of gas particles and the resulting pressure. Further to this a demonstration of the 'water fountain' was presented and discussed in an attempt to apply some of these concepts to a practical example of pressure change.

Step 3 - Application of knowledge

Working in groups the students completed and discussed the following activities:

1. Observing a plastic bottle partially filled with boiling water and sealed, collapse after a few minutes.

2. Pulling down the diaphragm of a model lung and observing what happens to the 'lungs.'

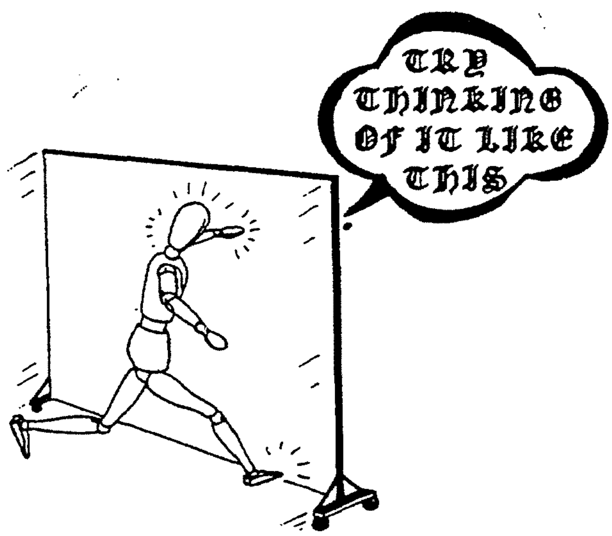
3. Inverting a glass beaker, placing it over a floating cork, then submerging the beaker.

Step 4 - Review

Students then presented the theories they had constructed in an attempt to explain the phenomena observed while completing the activities and these were discussed with the class. The analogy and the Kinetic Theory model were used to help provide a visual representation of the explanations.

Step 5 - Provision of the scientific view (single session).

The students received a handout on pressure (see Appendix D) containing the scientific view and other information which was discussed with the class.



When a running child collides with a screen it moves, because the child has pushed the screen, and thus a force has acted on it. Now imagine the same screen but instead of one child there are millions of air particles colliding with the screen. These colliding particles cause a pressure in the same way that the child produced a force when he collided with the screen. Why does the screen not move even when the air particles collide with it?

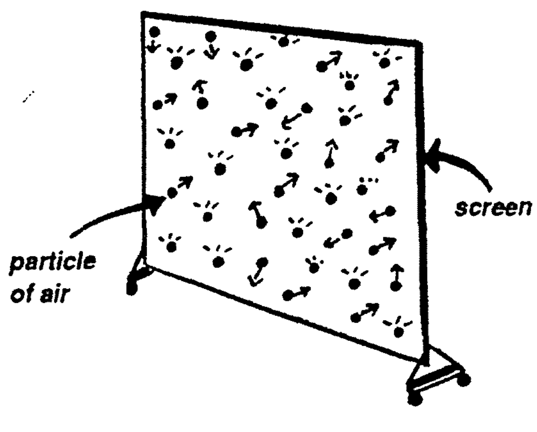


Figure 5.9. An analogy used to introduce the concept that gas pressure is caused by the collision of gas molecules with the walls of a container (after Pendlington et al., 1993).

5.3 Monitoring of the intervention

It was important to monitor the intervention and, in particular, the experimental group in order to verify that the intervention strategies were explicitly incorporated and followed in the instructional design and to establish how the students responded to the new teaching strategies. To this end the classes were videotaped throughout the intervention. As well as the use of video, two audiotape recorders were employed to monitor the discussion within the small groups during the practical sessions during both the control and experimental lessons. This allowed for a comparison of the discourse which occurred in the two treatments. The tape recorders were assigned randomly to groups within the classes each week.

Due to the volume of data, the tapes were selectively transcribed where issues of interest arose. However, all of the tapes were audited directly after each session as this allowed the researcher to determine how effectively the collaborative group work was being undertaken. It also indicated which concepts were causing particular problems and allowed the researcher to focus on these if necessary in the single lecture session which followed. The video recordings were viewed by the researcher to help confirm the treatments were being conducted differently, however, further use of the data was precluded due to poor sound quality on these recordings.

As part of the monitoring process a series of informal interviews was also conducted with the lecturer in science education at the Teachers' College. She acted as an independent observer for both groups throughout the intervention, and her views on the effectiveness of the various intervention strategies were recorded. She also reported informal feedback from the students which she picked up during the lessons. In addition this lecturer was able to confirm that the control and experimental treatments were different in their approaches.

The conducting of informal interviews with students from the experimental group during the intervention was also considered as part of the monitoring process. However, this idea was rejected as this would cause reflection on the individual strategies and thus metacognition amongst these students. Since it was not the intention to conduct similar interviews with the control group, it was felt that this procedure might bias the study. As such, the views of the experimental students as to the efficacy of the various teaching approaches were not solicited until after the post-test had been completed.

5.4 Summary

This chapter has outlined the rationale behind the experimental treatment and described how both the control and experimental treatments were implemented. As mentioned at the beginning of the chapter, it has in effect been an extension of the methodology, but because of the particular importance of the intervention to the study, this phase has been described separately. The next two chapters detail the results and analysis derived from the data collected during all four phases of the study.

Chapter 6

Results and Data Analysis of Elicitation and Prevalence Phases

6.1 Introduction

This chapter presents the data gathered during the initial two phases of the study, namely the elicitation phase and the prevalence phase. The data relate to the first two objectives:

1. To identify and compare the alternative conceptions held by individuals of both ethnic groups.

2. To determine the prevalence of these alternative conceptions in a wider population of pre-service teachers.

However, the chapter also provides baseline data on the students' conceptual understanding of matter and how it changes. Understanding this change is vital to the later phases of the research which involve the implementation and evaluation of a teaching experiment.

For each phase the method of analysis is outlined first and examples from the analysis procedure are presented. The results of the validation procedures outlined in chapter 3 are then discussed before the data obtained for each phase are presented. The analysis, validation and data representation are presented separately for each of the individual phases.

6.2 The elicitation phase

6.2 1 Analysis and validation of the data

6.2.1.1 Method of analysis

The taped interviews were transcribed directly after the completion of each interview. Since the intention was to extract concepts held by the student teachers, the researcher employed a method of analysis similar to that used by other workers in this field. Of particular relevance was the work of Erickson (1979), Hewson (1982) and

Rollnick (1988). In all these cases the physical layout of the analysis was similar. The transcript was printed on the left of the page and a blank space was allowed on the right for comments. The researcher favoured the method employed by Hewson (1982) and Rollnick (1988) which used two additional columns, one labelled interpretation and the other, classification. The interpretation column included an assertion, formulated by the researcher, of the assumptions and conceptions displayed by the subjects. These were then classified as scientific or alternate. A sample segment from an analysed transcript is presented in Table 6.1. The information from the analysed transcripts was then used to develop Concept Profile Inventories (CPIs) for each of the two ethnic groups represented in the interview sample.

6.2.1.2 Concept profile inventories

One of the stated purposes of the interviews was to construct inventories of the main scientific and alternate conceptions held by both Fijian and Indian students as this would allow for a comparison of conceptions across these ethnic groups. The pilot study conducted in Australia had provided a gross structure for the CPI comprising five major categories. These were: change of state of matter; conservation of matter; solubility; heat; and pressure. These major categories proved to be appropriate for the main study and as such remained unaltered. All of the conceptions that had been classified as scientific or alternate were extracted from the interviews and inserted verbatim into the CPIs. As with the pilot study, the researcher's assertions of these conceptions served as the subcategories that provided the internal structure for each category of the CPI. Once again the categories and subcategories were not mutually exclusive due to the broad range of topics covered in the interviews. As it was not practical to include all the conceptions expressed by the students, each CPI was condensed to provide single verbatim examples of the conceptions expressed in each subcategory, together with the number of students who held each conception. Each subcategory was then given its own code.

Table 6.1

Analysis of a Segment of the Interview with Subject FM1

Transcript	Interpretation	Classification
Card 1 **I:** This is the first card. Could you just tell me what you see happening in the card. **S:** In the first glass there are some ice cubes and in the second glass after 5 minutes the ice cubes have melted and after 10 minutes it has completely changed to liquid. **I:** Could you explain to me why melting takes place and how it happens? **S:** em...melting takes place because of the heat on the ice cubes and em that's why...the heat causes it to melt. **I:** Do you know why the heat causes it to melt? **S:** No. **I:** You're not sure? **S:** Yes.	S explains that heat energy is necessary for matter to change state from the solid form to the liquid form. However, S is unable to go beyond the macro level and explain the underlying concept using Kinetic Theory.	Scientific conception of change of state of matter at a macro level.
I: Do you see anything on the last glass, or after 10 minutes rather? **S:** I can see droplets of water. **I:** Could you describe to me where the water came from and how it got there? **S:** ...maybe because of the air particles from outside hitting the cold surface from within from the water that has just melted, and causes the droplets to form...the moisture, the droplets came from the air particles...which hit the cold surface and it eh when it cools it forms the droplets.	S is aware that condensation results from the presence of moisture in the atmosphere and indicates that this process may involve the conversion of one substance (air) into another (water).	Scientific conception of the origins of condensation.
I: You mentioned the term particles, the word particles...if I asked you again about the ice melting could you use that idea of particles to explain it? **S:** The ice, the ice cube...the particles are held closely together and when heat penetrates it the particles...tend to...I'm not sure. **I:** You're not sure? **S:** No	S mentions particles for the first time and is aware that they are closely packed in solids. However, he cannot explain how the behaviour of these particles is affected by heating.	Scientific conception of the particulate nature of solids.
I: Let's go back to this last picture. You think that the air particles touching the glass become water. **S:** Yes **I:** I wasn't quite sure if that was what you meant. **I:** When you say air particles, can you tell me how the water forms out of those air particles? **S:** Maybe when the air particles get to a certain temperature they change their form. **I:** I see.	S unsure of the formation of condensation and puts forward a theory that at a given temperature the particles of one substance can be transformed into those of another substance.	Alternative conception of change of state of matter at the micro or particle level.

Transcript	Interpretation	Classification
Card 2 **I:** What do see in this picture? This is the morning and this is the afternoon. **S:** In the morning it was raining heavily and you can see some puddles of water there and in the afternoon the sun...the sun came out and the puddles of water disappeared because of evaporation. **I:** You've used the term evaporation, could you describe to me how evaporation takes place?		
S: When the particles of water is being heated up they tend to get light and rise up into the air. **I:** So you think that the heating would cause the particles to get light? **S:** Yes **I:** Could you explain to me how that happens? **S:** No I'm not sure. **I:** OK is there anything else you can tell me about evaporation? **S:** ...no I don't think so.	S is aware that heat is necessary for evaporation to take place, but possibly because he knows that hot air rises due to its reduced density, he has transferred this idea to the particles of water to explain how they enter the atmosphere.	Scientific conception of change of state at the macro level. Alternative conception of conservation of mass of water particles.
Card 3 **I:** Perhaps you could tell me what you see inside this boiling kettle? **S:** Can see some bubbles inside the boiling kettle. **I:** What do you think the bubbles might be made from? **S:** From air. **I:** And how do you think they were formed?		
S: They were formed from the particles of air in the water being heated up. **I:** Could you take that a bit further?	S believes the bubbles in boiling water are air rather than water vapour.	
S: Eh maybe its the same thing like evaporation, when the water particles are heated up they tend to get light so they turn to air particles, and they rise up as bubbles. **I:** And what do you think this is? (Steam) **S:** That's the air particles escaping through the mouth of the kettle. **I:** And where do you think those have come from? **S:** It comes the same, from the water bubbles. **I:** So the bubbles go to the surface... **S:** Yes and try to come out. **I:** I see.	S applies two previously stated alternative theories to explain the view that air bubbles come from water, namely that the particles of a substance are transformed and made lighter by heating.	Alternative conception of change of state of matter at the micro or particulate level.

A segment of the CPI constructed for the Fijian students is shown by way of an example in Table 6.2. The condensed CPIs for both ethnic groups are presented as appendicies (see Appendix E for Fijian CPI and Appendix F for Indian CPI) with the expanded versions containing all the expressed conceptions being held as raw data.

Table 6.2

Subcategory E of the CPI Constructed for Fijian Students showing Scientific and Alternative Conceptions held about Solubility

E. Conceptions about solubility

Scientific conceptions

E.1.1 A solution consists of one substance mixed thoroughly with another (4)
'The sugar particles just mixes with water...just mixes in between.' **FM4**

E.1.2 Dissolving a solute in a solvent is a reversible physical change (6)
'after some time the water will evaporate and the sugar will be there.' **FF6**

E.1.3 Saturation occurs when no more solute will dissolve in a solvent (5)
'I guess there's no more space so it (the water) just can't take any more sugar.' **FM4**

Alternative conceptions

E.2.1 Dissolving associated with melting (2)
'The sugar (in water) will melt...the sugar particles have turned to liquid.' **FF3**

E.2.2 Dissolving is an irreversible process (5)
'Because water is a liquid and you just can't get anything back.' **FM4**

E.2.3 Some matter within a solute is too concentrated to dissolve (2)
'These particles here they're too closely attached and it doesn't allow space for the water to get through and make it soluble.' **FM6**

E.2.4 During dissolving sugar absorbs water (1)
'Sugar absorbs water and causes the particles to disintegrate and eventually it turns to liquid.' **FM6**

E.2.5 During dissolving the solute changes chemically (2)
'It (the sugar) changes into liquid...it changes into water.' **FF5**

E.2.6 Saturation explained as impurities (0)

E.2.7 Dissolving attributed to abrasion or attrition (0)

E.2.8 Dissolving attributed to air spaces between water particles (0)

Note: The number in brackets represent the number of students who held a particular conception. Where a bracket contains zero, the conception was present amongst the Indian sample but not amongst the Fijian sample. The coding FM and FF refers to Fijian male and female respectively, with each student allocated a reference number (see Table 3.1 of section 3.4.1.1).

6.2.1.3 Categorising students' use of molecular models

In addition to identifying and classifying students' conceptions about changes in matter, the researcher attempted to categorise the extent to which the students applied a molecular model to their explanations of the phenomena provided. To this end each student's explanation of the cards and activities presented was carefully examined and coded according to the following scheme:

1. Energy (E) = Student makes either explicit or implicit reference to energy during the explanation. This does not simply include using the word energy, but also reference to any form of energy such as heat or movement.

2. Particles (P) = The student makes implicit or explicit reference to atoms, molecules or simply the term particles during the explanation.

3. Partial Molecular Model (PMM) = The student makes reference to both energy and particles during the explanation, but fails to make explicit the link between them e.g., 'the particles move apart.'

4. Complete Molecular Model (CMM) = The student makes explicit reference to the relationship between energy and particles during the explanation e.g., 'the particles gain energy when they are heated', and has applied a Kinetic Theory of matter.

Clearly if students did not incorporate the term particle into their explanation and made some reference to energy they could not be coded as using either a partial or complete molecular model.

Once all of the transcripts had been coded, the data for each ethnic group were extracted and presented in Tables 6.8 and 6.9 later in this chapter. This allowed easy comparison of the extent to which the two groups employed Kinetic Theory in their interview explanations.

6.2.1.4 Validation of interview analysis

The Concept Profile Inventories were used to validate the analysis of the interviews. In order to complete the validation, a panel of six judges was selected by the researcher. These judges were chosen for their knowledge of science and their experience of teaching this discipline in Fiji. Table 6.3 summarises the background of the judges. Two interview transcripts were used in the validation process, one being randomly selected from each ethnic group. Sections of these two sample transcripts were then given to the six judges. Since many of the complete interview transcripts were over fourteen pages long, and would have taken the judges considerable time to analyse, it was decided to use a section (approximately one third) from each of the two transcripts. This was considered sufficient material with which to conduct the validation effectively. The selection contained the students' explanations of cards 1, 2, 3 and 6 which covered a variety of changes of state in different contexts as well as their views on solubility. The identity of the students was not revealed to the judges.

Table 6.3.

The Background of the Judges used in the Validation of the Interviews

Judge	Background
J 1	Lecturer in science education with extensive experience teaching biology and Basic Science at Fiji high schools (Fijian).
J 2	Former senior lecturer in science education with extensive experience in teacher education and high school chemistry teaching (Indian).
J 3	Lecturer in physics at the University of the South Pacific who had conducted a considerable number of in-service workshops with Fiji teachers (European).
J 4	Teacher of biology, chemistry and Basic Science at a local high school in Lautoka (Indian).
J 5	Head of physics and mathematics at a local high school in Lautoka (Indian).
J 6	Teacher of biology and chemistry at a local high school in Lautoka (Indian).

In addition to the transcripts and instructions, the judges were provided with copies of the expanded CPIs which contained all of the statements provided by the students in each subcategory, plus copies of the appropriate cards. They were then required to complete two tasks. Firstly, they were asked to read the transcripts of the explanations of each card and code them using the E, P, PMM and CMM criteria outlined above. Secondly, they were to identify any scientific or alternative conceptions which appeared in the transcripts and match these to the subcategories within the CPIs using the coding scheme provided. The instructions to the judges along with a copy of the transcript for student FF3 are presented as an appendix (see Appendix G). Their results were then compared with the analysis of the two transcripts completed by the researcher and the percentage agreement between the researcher and the judges for the two sample interviews was calculated. Where discrepancies between the researcher and the judges appeared, these were negotiated whenever possible, in order to reach a consensus. The results of the validation are shown in Tables 6.4, 6.5 and 6.6.

Tables 6.4 and 6.5 indicate the agreement between the researcher and the judges on the extent to which a molecular model was applied to each explanation.

Table 6.4.

Percentage Agreement between the Researcher and the Judges on the Coding for Molecular Models within Sample Transcript 1 (IF1)

Card	Code	E	P	PMM	CMM	Agreement
1	Researcher	✓	✖	✖	✖	
	Judges	6/6	6/6	5/6	6/6	96%
2	Researcher	✓	✖	✖	✖	
	Judges	6/6	6/6	6/6	6/6	100%
3	Researcher	✓	✓	✓	✖	
	Judges	6/6	6/6	3/6	3/6	75%
6	Researcher	✖	✓	✖	✖	
	Judges	6/6	6/6	2/6	6/6	83%

Note: Refer to Table 3.1 of section 3. for the science background of subjects IF1 and FF3.

The ticks (✓) entered in the researcher's rows represent the coding he applied to the explanation for that particular card. Where a cross (✖) occurs the researcher judged that the particular model was absent. The degree of agreement between the judges and the researcher is shown as a percentage.

Table 6.5.

Percentage Agreement between the Researcher and the Judges on the Coding for Molecular Models within Sample Transcript 2 (FF3)

Card	Code	E	P	PMM	CMM	Agreement
1	Researcher	✖	✖	✖	✖	
	Judges	6/6	6/6	6/6	6/6	100%
2	Researcher	✖	✖	✖	✖	
	Judges	5/6	6/6	6/6	6/6	96%
3	Researcher	✖	✖	✖	✖	
	Judges	6/6	6/6	6/6	6/6	100%
6	Researcher	✖	✖	✖	✖	
	Judges	6/6	4/6	6/6	6/6	92%

Table 6.6 presents the specific scientific and alternative concepts identified in the transcripts and coded from the CPIs, along with the percentage agreement between the researcher and the judges.

Student FF3 proved to be an extreme case with no apparent conceptualisation of a molecular model, and as a result, in the view of the researcher she made no reference to particles or energy in any of her responses.

Although the overall agreement between the researcher and the judges on the coding for molecular models was generally good, there were a number of anomalies which required reconciliation.

For card 3 of transcript IF1, there was some contention as to whether the subject had employed a complete or partial molecular model in her explanation of boiling. The student had stated that:

> ...once they are heated the particles expand and then try to move apart, and due to that movement the bubbles are formed...

The researcher felt that the subject had not made explicit the gain in energy by the particles and as such coded the explanation as a partial molecular model. However, three of the judges felt that this explanation represented a complete model.

This was clearly a difficult interpretation and as such was not easily resolved. In addition two judges coded the explanation of card 6 by this subject as representing a partial molecular model. However, as they included no code for energy, this was taken to be an error of judgement on their part.

In card 6 of transcript FF3, the subject had used the term particle as follows:

> The sugar particles have turned into liquid.

The researcher interpreted this to mean particles used not in the molecular sense but rather in the granular sense. However two of the six judges interpreted it as referring to molecules. When this issue was checked with the subject, she confirmed that she had been using the term particles in the macro sense to refer to sugar grains or crystals.

Table 6.6.

Percentage Agreement with the Judges on the Coding of Conceptions from the CPIs within the Sample Transcripts

Card	Agreement on transcript IF1	Agreement on transcript FF3
1	A.2.1: 100% A.2.2: 71%	A.1.4: 100%
2	A.1.1: 86%	A.2.4: 100%
3	A.1.1: 100% A.2.8: 100% B.1.1: 43% D.1.2: 100% D.2.1: 100% (one judge also included A.1.5, while another included A.2.2)	B.2.5: 100% (one judge also included A.2.1)
6	E.1.2: 71% E.1.3: 86% E.2.2: 100%	E.2.1: 86% E.2.2: 100% E.2.5: 100%

Note: Refer to the CPIs presented in Appendices E and F for the alternative conceptions which correspond to the codes provided in the table.

Again, although overall agreement on the coding of the concepts within the transcripts was generally high, the response to card 3 of IF1 gave some cause for concern as the agreement between the judges and the researcher on the presence of conception B.1.1 was only 43%. In this case the student had, in a series of statements, confirmed that the water in the kettle when boiled turned into water vapour.

> I: So if I asked you what the bubbles are made of what would you say?
> IF1: The bubbles would be made of water itself with the help of heat.
> I: So they are made of water itself?
> IF1: Yes sir, due to the heat being used there.
> I: But are they gas or liquid bubbles?
> IF1: Inside the kettle I would say it's liquid, but once it's going I'd say it's forming into vapour...steam.

This, in the view of the researcher, indicted that the student understood that when a change of state took place the composition of its particles remained the same, as asserted in B.1.1. However, when asked about this, those judges who had failed to include it claimed they had either simply overlooked this conception, or had been unsure whether to include it or not.

Despite the differences in agreement highlighted above for the two validation tasks, the overall agreement in each case was well in excess of the 75% figure used by Rollnick (1988), and it was deemed that the agreement on molecular model and concept classification was satisfactory.

6.2.1.5 Analysis of additional information from the elicitation phase

As mentioned in chapter 3, in addition to probing the students' conceptual understanding of matter, the elicitation phase also yielded data on the students' views on the nature of science, the learning environment, and their traditional beliefs.

Each of these three additional topics covered in the interviews was treated separately. For each topic an individual computer folder was created. After reading the transcripts many times, a number of categories were identified as emerging from the data within each of the three topics and an individual file created for each category. Then sections from the interviews pertaining to a particular category, were copied into the appropriate file, and the files were stored together within their folder. For example, a folder was created for the topic 'Nature of Science.' This comprised three files entitled, 'the meaning of science', 'the role of scientists' and 'scientific proof.' Thus, when students were asked, 'If a friend asked you to explain exactly what science was, what would you tell them?', their responses were filed under 'the meaning of science.' The categories developed for 'The Learning Environment' were: 'the role of the teacher'; 'the role of questioning'; 'competitive versus co-operative classes'; 'the role of the examination system', while those for 'Traditional Beliefs' were 'traditional view'; 'mixed view'; and 'scientific view.' This information is summarised in Table 6.7.

Table 6.7.

A Summary of the Additional Information obtained during the Elicitation Phase Showing the Three Major Categories (Folders) and their Subcategories (Files)

Traditional Beliefs	Nature of Science	The Learning Environment
Traditional view	The meaning of science	The role of the science teacher
Mixed view	The role of scientists	The role of questioning
Scientific view	Scientific proof	Competitive versus collaborative classes
		The role of the examination system

In describing and discussing the findings of these sections of the elicitation phase later in this chapter, specific excerpts of dialogue were extracted from the appropriate categories and used to support the assertions being presented by the researcher.

6.2.2 Results of the elicitation phase

A summary of the results of the molecular model analysis for both ethnic groups is presented in Tables 6.8 and 6.9. The CPIs constructed for both ethnic groups show the range of conceptions that came out of the elicitation phase together with the frequency with which they occurred. Some of the qualitative responses of the subjects are examined in more detail below. This has been done on a card by card basis. Where segments of dialogue are used to exemplify certain points, **I** refers to the interviewer, while the subject is referred to as **S**. However, the particular subject's code is also given e.g., **FM1** (Fijian Male 1) as this allows the reader to consult Table 3.1 in section 3.4.1.1, which provides a record of each subject's science background.

Table 6.8.

Fijian Pre- Service Primary Teachers' use of Kinetic Theory in Explanations (n=12)

	Ice in glass	Rain Puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & Ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	3	3	3	1	2	2	5	3	7	9	3	2	1
Reference to energy	8	11	9	8	5	6	9	7	n/a	11	n/a	5	n/a
Partial molecular model	3	3	2	0	1	0	4	1	2	7	1	2	0
Complete molecular model	0	0	0	0	0	0	0	0	3	0	0	0	0

Table 6.9.

Indian Pre- Service Primary Teachers' use of Kinetic Theory in Explanations (n=12)

	Ice in glass	Rain Puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	6	9	7	3	8	1	9	7	11	12	7	8	4
Reference to energy	11	12	12	12	7	6	12	9	n/a	12	n/a	10	n/a
Partial molecular model	2	7	4	2	4	0	5	4	4	7	5	4	1
Complete molecular model	4	1	2	1	1	0	4	0	6	3	0	4	0

6.2.2.1 Card 1 A glass of ice cubes

The purpose of this card was to explore the subjects' ideas about the change of state from solid to liquid, and in addition their notions about the gas/liquid transitions.

While most students were aware that heat energy was required to initiate the melting of ice cubes, one student associated melting with exposure to light, and another related it to atmospheric pressure and the presence of humidity.

> I: Do you know what causes the ice to melt?
> S: ...like the ice it's exposed to the light and when it's exposed to the light it starts to melt. (FM6)
>
> I: Can you explain to me what happens when the ice melts?
> S: At first when you put the ice in a beaker or in a jar, it encounters the atmospheric envir...atmospheric pressure and all those...as soon as it encounters that the cubes they start to melt. The longer you put the cubes in this situation...I mean this humidity, I mean it will melt at that rate. (IF3)

When asked to explain how the process of melting took place one of the Indian subjects and five of the Fijian subjects could offer no response, claiming they did not know. Others attempted to apply Kinetic Theory to their explanations, but often the model they employed was incomplete, as it failed to make an appropriate link between particles and energy. For example this is evident in the following exchange with IM1.

> I: how does the heat cause melting to take place?
> S:...it causes the water particles to expand whereas when it freezes to ice it contracts and it gets together and eh when exposed to heat it eh moves far apart and it melts.
> I: Why do they move far apart...the particles?
> S: They move far apart because eh...they get to the normal size, that means...it's far apart in the liquid form and when solid forms it gets together so that it has back to its normal size...(IM1)

At this point it is important to stress that, although the standard of the students' English was generally very good, there were occasional differences in the usage of terms. Thus for example, when the subject above referred to the particles expanding, this was not an alternative conception as it is clear from the transcript that he meant that they separated or moved apart rather than getting bigger in size. For example:

> I: When you say the particles expand do you mean that each particle gets bigger, or they move apart, or they get bigger and they move apart?

S: No, they simply move apart from each other, they don't expand or get smaller (IM1)

As such it was very important to get strict clarification of the interpretation of certain terms, particularly as some students also applied them in different ways to others.

Only four students, all Indian, managed to provide an explanation of melting which incorporated both particles and energy in a way which made the link between these concepts explicit:

I: How exactly does the heat cause the ice to melt?
S: Those particles move away a bit due to the energy given to them by the increase in temperature...that means the particles have gained enough energy to move apart and form liquid...(IM6)

I: Could you say anything more about the process of melting?
S: When we heat anything that means we're providing the energy and the particles they tend not to want to stay together, so as soon as they get their energy they want to leave their partners and they move apart and that's why they start melting (IM3)

The use of anthropomorphic language such as that by subject IM3 was commonplace amongst the students and teachers alike in Fiji.

S: That water comes from the surroundings, because the surface of the beaker is very cold, water droplets in the surroundings, they get to the sides of the glass.
I: Why does that happen?
S: They find it very suitable so they come in contact and they form water droplets (IF4)

While for some this was simply a means of expression, others like the subject above (IM3) tended to view the particles of matter as living entities.

S: The energy...that helps the particles to get a wider space, in other words provides the form of heat or the form of food...like we eat food so we get the strength in our bodies...the same thing here, the energy provides the strength to the particles to move and take up space.
I: So the energy helps them to move? Do you think of the particles as living or non-living things?
S: They're living things (IM3)

The concept of condensation proved to be extremely problematic for students to explain scientifically. Although half of the students knew that condensation forming on a cold surface was derived from the atmosphere, this being a very common phenomenon in Fiji's humid climate, other students believed it came directly from the ice cubes, or through the glass or attributed it to the effect of atmospheric pressure.

One student appeared to generate spontaneously his own alternative framework to explain condensation.

> S: The droplets came from the air particles...which hit the cold surface and it eh when it cools it forms water.
> I: When you say air particles, can you tell me how the droplets form out of those air particles?
> S: Maybe when the air particles get below a certain temperature they change their form (FM1)

This subject proceeded to apply this framework with considerable consistency to explain other phenomena he was presented with later.

The majority of students (15) could offer no explanation for the formation of condensation. Of the remainder only two provided an acceptable explanation involving the application of Kinetic Theory.

> I: Where have those water droplets come from?
> S: Those are from the humidity from the atmosphere...the water particles in fact are in gaseous form and when they touch the cold surface they become liquid water.
> I: Why do they become liquid?
> S: They are losing energy there (IF6)

The other students who attempted an explanation could only do so at a macro-level.

6.2.2.2 Card 2 Rain puddles

The purpose of this card was to probe the students' conceptions of the liquid/gaseous transition of matter. The majority of students (18) used the term evaporation in their description of the phenomenon depicted. However, of these, eight students simply stated that the puddles had evaporated and could not enlarge on this further.

> I: Where have the puddles gone?
> S: They've evaporated.
> I: Why does that happen?
> S: Because of the heat in the environment.

I: So how does the heat actually cause evaporation to take place?
S: I'm not sure (IM4)

The most common alternative conception was the view that the heat or the sun's rays had absorbed the moisture in the puddles. This view was most common amongst Fijian students (5) but was also held by some Indians (2)

I: What has happened to the puddles in the afternoon?
S: Because the sun shines and the heat goes back to the sun...the liquid goes back to the sun. But the sun's rays is very strong.
I: And how do you think the sun's ray make the water go back up?
S:...I think by absorbing it...
I: You think the sun's rays...
S: Absorb the liquid...the water (FF4)

One student claimed that evaporation and boiling were the same because he believed steam was produced during each process. Other students (2) suggested evaporation occurred because the water particles lost mass as a result of heating.

I: You've used the term evaporation, could you describe to me how evaporation takes place?
S: When the particles of water is being heated they tend to get light and rise up into the air.
I: So you think that the heating would cause the particles to get light?
S: Yes.
I: Could you explain to me how that happens?
S: No, I'm not sure (FM1)

Conceptual models of evaporation were generally presented in terms of increased spacing between the water molecules (11), rather than energy gain.

I: You said they evaporate...what does the heat do to make them evaporate?
S: Em...I think it causes the water particles to move again far apart and then it changes to vapour and gets into the atmosphere (IM1)

Only one student provided what was considered a complete molecular model, linking energy to increased particle movement.

I: How exactly does the heat cause the puddles to evaporate?
S: It eh gives...adds more energy to the it eh then the particles gain more energy and move faster and farther apart and then they become vapour (IF6)

However, as with all the other explanations there was no reference to water particles needing to gain sufficient energy to overcome the cohesive forces within the liquid to enter the vapour phase.

6.2.2.3 Card 3 Boiling kettle

This card probed the students' conceptions about the change of state of water from liquid to gas, and the conservation of matter during this process. The card prompted a large number of references (23) to an input of energy into the water and most of these asserted that the heat energy was derived from electricity.

> I: Do you know how the bubbles were formed?
> S: Just from the heat energy from the electric of the kettle...from the heat that takes place from the electricity...after you left it for sometime you could see the bubbles coming up (IM2)

However, only ten of the students also incorporated a reference to particles into their explanation.

The most common alternative conception related to the content of the bubbles with the majority of students (18) claiming that the bubbles were formed from air, even though it was stressed by the researcher that the kettle had been boiling for some time. This conception was equally prevalent amongst Indian and Fijian students. A number of theories were presented to explain this. Student FM1 applied frameworks from two previous explanations to account for the presence of air in the bubbles.

> I: Can you say anything more about how the bubbles were formed?
> S: Eh maybe it's the same thing like evaporation, when the water particles are heated they get light so they tend to turn into air particles and they rise up as bubbles (FM1)

This view that water changes to air when heated was shared by two other students, one Fijian and one Indian. In fact the Indian student defined boiling as the point at which water changes into air.

Another common theory (6) was that the gaps between the water particles were occupied by air and during boiling the air particles moved apart creating bubbles.

> I mean the water particles are a bit separate, you know a bit far apart, so in between them there are air par...I mean air. So when you heat it the air expands and forms bubbles (IM5)

Others thought the bubbles were composed of air and water (2), or formed from a vacuum (1), while one student believed the bubbles were formed by air particles in the water growing larger when heated. Only two students were aware that the bubbles contained water vapour. Although most students claimed the bubbles in boiling water were composed of air, with the exception of two students who thought air and steam were the same, the others distinguished between air and the steam coming from the spout which they recognised as being formed from water. These students either appeared to see no conflict between bubbles of air and the presence of steam at the spout, or claimed that they could not explain it.

Perhaps surprisingly, no one from this sample held the conception that water broke down to its constituent elements (hydrogen and oxygen), as this view was common amongst the Australian students interviewed in the pilot study.

Only two students, both Indian, could provide an explanation consistent with the scientific view of bubble formation during boiling.

> S: There is a gain in energy from the electric kettle and the particles of water separate and there is a change of phase. So because of the increased gap between the water particles, bubbles are formed (IM6)

6.2.2.3 Card 4 The cold window pane

This card was designed to elicit the students' views about water in the gaseous state and the nature of its change back to the liquid state.

In general the students found this card particularly difficult to explain. Only four students incorporated particles into their explanations, and although most (20) made some reference to energy, only six actually referred to a loss of energy occurring when the steam hit the cold window. Seven students could make no attempt at explaining condensation and most of the explanations given were either extremely confused or presented at a macro level.

> S: The steam forms water?
> I: Why does it do that?
> S: It's the same as when water boils...it evaporates...the water vapours when they come in contact with a cool surface it changes back into water as water droplets.
> I: How exactly does that happen?
> S: Because it's hot...I mean not that hot but warm and when it comes into contact with the cool surface it changes into water (IF3)

One student stated that the glass was sweating because of the heat (sweating is a commonly used analogy for condensation in Fiji, which is often taken literally). Another believed that the condensation had occurred because the window acted as a barrier causing a build up of steam.

> I: Do you know why the steam is changing into water in this picture?
> S: I think because of the window, the steam is coming out and the window blocks it so the steam accumulates and it's like the process of precipitation...the steam accumulates, it's heavy and no longer can hold its water, so it starts to fall down as water (FM6)

Part of the difficulty in explaining this card may have arisen because the phenomenon depicted on the card of vapour condensing on a cold window pane was rarely observed in Fiji. In fact one student commented that it was the first time she had encountered this.

Having said this, three students were able to provide explanations which were close to the scientific view with one alluding to latent heat.

> I: Why does condensation take place?
> S: Condensation takes place because there is a release of heat energy. There is a release of heat energy and the water particles come together (IF4)

6.2.2.4 Card 5 Dissolving sugar in water

This card was intended to probe the students' understanding of solubility and saturation. A total of twelve students were able to state that dissolving involved the mixing of sugar with water. Of these, six were able to explain the processes in terms of a coherent conceptual model involving particles.

> I: When you say the sugar has dissolved what does that mean?
> S: The sugar particles mix with the water particles.
> I: Where do the sugar particles go?
> S: They just mix...there are gaps between the water particles and the sugar particles fill these (IM4)

Only one student attempted to explain dissolving in terms of attraction and bonding between sugar and water molecules.

> S: So in warm water the reaction will happen faster because of the higher energy. What happens is the sugar particles are attracted to the polar

> water...I think the sugar particles are hydrophilic...they sort of follow the water particles and mix around with them...they get bonded...attracted to the water particles (IM6)

However, this view led to problems later when the same student attempted to explain saturation.

> S: These crystals...these must have been eh very close hard packed crystals that hasn't got dissolved due to less energy given to them...I think there wasn't sufficient energy given to them...because the bonding in those crystals was too strong (IM6)

This view of saturation was also shared by two Fijian students, while one Indian student related saturation to impurities. However, half of the students (12) held the scientific view that saturation occurred when no more solute will dissolve in the solvent because there was no more space left between the particles of solvent. Three students believed that the sugar had to melt before it could dissolve and one student expressed the view that dissolving involved the sugar changing into water.

While most students (15) were aware that dissolving sugar was a process which could be reversed by evaporating the solvent, seven believed it was a permanent change. Although almost all the students had completed a similar activity at high school with salt solution, it seemed that these individuals could not readily make connections with this knowledge.

> I: Do you think that this process is reversible.
> S: ...no it's a permanent change sir...if it had been salt then we could have reversed it because we would have evaporated the water and the salt would have been left at the bottom.
> I: And you don't think that's possible with sugar?
> S: ...no (IF1)

6.2.2.5 Card 6 A burning candle

This card was designed to explore the students' understanding of physical and chemical change and to test their ability to distinguish between these changes in the same substance. Generally, the term weight was used during this segment of the interview as many of the students were unfamiliar with mass.

Only three of the students attempted to use molecules or particles in their explanations of burning and melting, and in each case the model applied was inappropriate. However, half of the students incorporated energy when explaining these phenomena, in particular melting. No student was aware that vaporisation of the wax was necessary for combustion to take place, claiming the wax nearest the flame simply melted. In fact only five students were aware that the wax in a candle actually burned.

> S: In burning part of the wax is burnt off, so the actual amount is less...in melting it's the same (FM4)

Of these, two attempted to explain the combustion process in terms of its products, one suggested that carbon was produced while the other mentioned smoke.

The most common alternative conception (15) was that the wick was the only part of the candle which burned and, as such, the wax simply melted and resolidified. This view was equally common amongst Fijians (7) and Indians (8). This conception led, in turn, to the view that the mass of the candle remained unchanged after several hours of burning.

> I: If you were asked about the mass of the candle before and after burning what would you say?
> S: It would be the same.
> I: Why do you think that?
> S: Because nothing has been lost, it's just a change of state.
> I: So what do you think burns in the candle?
> S: It's the string, but the wax is like that, it just changes shape (IF3)

Of those who did suggest the mass of the candle had changed, this was generally attributed to factors other than combustion, such as energy loss or evaporation.

> I: Do you think you would find a difference in the weight of the candle before and after burning?
> S: If we weighed it we'd be able to get it (laughs).
> I: But if you had to predict.
> S: I'd say it won't be the same because it has melted and most of the energy would have been lost so it must be lighter in weight now.
> I: So you think it would be lighter because it lost energy?
> S: Yeah (IF1)

One student believed that the mass of the candle increased after burning.

I: Would there be any difference in the weight of the candle after it had been burning for some time?
S: I think this one (burnt) would be heavier.
I: Why do you think that?
S: Because the candle it melts it expands and there'll be more weight in this one (FM5)

This student had successfully completed Form 7 (Year 13) chemistry but appeared unable to apply his knowledge from that course, concentrating instead on the surface features of the problem.

Almost all the students (19) were aware that burning and melting were different types of process. This was usually explained in terms of reversibility, or the fact that burning resulted in new products while melting did not.

I: Do you think there is any difference between burning and melting.
S: Yes.
I: What is the difference?
S: Because burning completely changes the substance into something else, and melting is the same substance but in a different form (IM2)

However, this knowledge often proved to be very tentative and students would change their views readily.

I: Could you explain the difference between melting and burning?
S: I mean eh melting involves a solid turning to a liquid, but burning maybe it involves oxygen.
I: So you think melting wouldn't involve oxygen?
S: Maybe that involves oxygen too (FF5)

With the exception of one student who thought that wax turned into water when it melted, all of the others were aware that the chemical composition of a substance remained unaltered by a physical change.

6.2.2.6 Card 7 Bottle and balloon

The purpose of this card was to explore the students' views on gas pressure and how it is affected by changes in temperature. In total, fourteen students employed the concept of particles in their explanations, with nine of these (4 Fijians and 5 Indians) applying a partial molecular model to the problem. This generally involved the notion of heat making air particles move apart, but failed to link this explicitly to the gaining of energy.

> I: You said the heat causes the pressure to increase, how does heat cause pressure to increase?
> S: Due to the heat from this hot water, this bottle became hot and once the bottle became hot, the air that was inside this bottle expanded, the particles they expanded and once it expanded it tried to move up, then it went inside the balloon which stretched.
> I: I'm sorry to keep asking you this, but by expanded do you mean the particles got bigger or they moved apart or...
> S: They moved apart, they took up more space (IF4)

Four students, all Indian, were able to offer a complete molecular model.

> S: ...after the same bottle was placed in the hot water, so those particles which were in the bottles they have gained energy from the hot water outside...they gained energy and they start moving faster and they have expanded the balloon (IF6)

The remainder could provide only a macro level explanation in which they were unable to apply Kinetic Theory to explain the underlying mechanism which led to gaseous expansion.

> I: Can you explain why that has happened?
> S: Yes the heat...the heat is causing that...the heat that is in the hot water causes the bottle to get hot and the air which is in the bottle will be heated and it will expand, which will cause the balloon to be expanded...to be in this form.
> I: Do you know why the heat has that effect on the air.
> S: ...When heat is exposed to air, the air will try to get out...it will...when it will try to get out, it will reach the top, that's why the balloon gets expanded.
> I: Could you say anything more about that?
> S: ...No (IF2)

In this case the student offered an anthropomorphic reason rather than a molecular one in an attempt to justify her initial explanation. Once again, in explaining this card, the use of anthropomorphism was common (9). However, as mentioned previously, while some students actually believed the particles of matter were living, some simply used anthropomorphic language as a means of expressing themselves.

> S: The particles try to use up all the space inside so since the bottle is very small so that space, they can't use that small space, so they want to go out,

so they look somewhere to find space so they can move out.
I: Do you think of the particles as living or non-living?
S: Living (FM5)

S: There are more particles up here (in the balloon).
I: Why is that?
S: Because they are trying to escape.
I: Why do they try to escape?
S: Because they gained more energy and they can't stand still now. They want to move away.
I: Do you think of the particles as living or non-living.
S: The particles...they are non-living.
I: In the Hindu religion are all things viewed as living?
S: Not all things?
I: What about rocks?
S: Yeah they are.
I: And the particles which make them?
S: I see the particles as non-living (IF6)

Among the more common alternative conceptions associated with this card was the view that, upon heating, the air particles ceased to move randomly and accumulated in the balloon (6). This view was most prevalent amongst Fijian students (5). Others (2) viewed the inflation of the balloon as a permanent change which would not be reversed by removing the bottle from the hot water but only by removing the balloon from the bottle. Finally one Indian student who had consistently indicated that particles moved apart when heated, but who failed to link this to energy gain, appeared to generate a spontaneous framework by way of explanation.

S: Heat causes the particles to get positive charges and due to the charging of the particles they repel and that's why the balloon expands (IM1)

6.2.2.7 Card 8 Acetone in a sealed tube

This card was intended to probe the students' views on the conservation of matter and mass within a closed system. In explaining this card ten students applied the concept of particles or molecules. Indian students (7) used this concept more frequently than Fijian students (3). Although most students believed that matter was conserved during the physical change, three believed the acetone became air and one believed it was transformed into water. However, there was a marked difference between the two ethnic groups when discussing the concept of mass conservation. While all but three Indian students were aware that the mass of the two tubes would be the same and could readily justify this, six Fijian students claimed that the mass of the substance would change during the transition from one state and two stated that they were unsure if a change would occur or not.

> S: From the diagram I can see that due to heat the acetone particles that were in liquid form after heating they moved apart and the gap between them increased...and after five minutes of heating they change into gas particles.
> I: If you took the mass of this and the mass of this what do you think you would find?
> S: I don't think there would be much change in mass.
> I: Would there be any change in mass?
> S: No I don't think so...it should be same because of the complete seal.
> I: Why is that?
> S: That's stopping any gas particles or anything from getting out (IM6)

> I: If you were to weigh both tubes what would you find?
> S: This would be lighter.
> I: Why is that?
> S: Because gas is eh...you can't really see gas...and it's weightless and this is liquid and you can weigh it (FM5)

This may have been, in part, attributable to fewer Fijians employing a molecular framework when thinking about this problem and concentrating instead on physical attributes. However, some Fijian students did use a particle or molecular framework to explain one aspect of the card, namely evaporation, but then appeared to revert to a macro-level view when discussing the mass.

Two students, one Indian and one Fijian believed that the change of state shown was irreversible, while one student interpreted the change as chemical rather than physical.

> S: The acetone and the air of course will have the same weight as this one because it's just a matter of the air and the acetone being joined together.
> I: Joined together do you mean mixed?
> S: Not mixed, bound together.
> I: You think they bind together, the particles of air and the particles of acetone?
> S: Yes (FF1)

As mentioned in chapter 3, a procedure known as 'predict-observe-explain' was also employed to probe the students' understanding of matter. This used a series of five practical activities which supplemented the IAI cards. Samples of the students' response to these activities are provided below.

6.2.2.8 Activity 1 Air and water filled syringes

This activity was designed to probe the students' mental models of the particles in liquids and gases. When asked to predict the outcome of pressing the plunger on sealed syringes containing air and water, more than half of the students (14) (5 Fijian and 9 Indian) made the correct prediction with the appropriate explanation. The most common alternative conception amongst the predictions was that neither substance could be compressed (8). Upon completion of the task, seven of these students, plus one who predicted that only the syringe containing water was compressible, appeared at least to recall the scientific view, if not to undergo conceptual change.

> I: What do you think you will find?
> S: You can't push in either (plunger)
> I: OK you can try it.
> S: Oh.
> I: So can you think why it was different from your prediction?
> S: Maybe it's to do with the difference between air and water.
> I: How are they different?
> S: In water I would say the particles are close together but in air they are far apart...so when we press the water, because the particles are a bit together...so we can't press it...whereas this one the particles are far apart...when we press it the air particles inside here they come together so they use up the space (FM5)

It appeared that this student had made his prediction without applying a conceptual model incorporating particles and their spatial distribution in liquids and gases, even though he clearly possessed such a model. When asked about this the student agreed but could offer no explanation as to why his view had changed.

One student who had predicted incorrectly believed that the conflicting observation was due to an anomaly, and as a result held to her original view.

> S: Some of the air must have gone out, because if there's some inside I wouldn't be able to do this (squeeze the plunger) (FF3)

Two other students, having predicted that air was not compressible, resolved the conflict by stating that air had no physical characteristics.

Ten students (3 Fijian and 7 Indian) were aware that there is a vacuum between the particles of a gas, although they were not all familiar with the scientific term.

I: You mentioned particles and spaces between the particles, do you think there is anything in those spaces?
S: There wouldn't be anything inside that space, that's why we are able to compress it. If there had been something inside it would have been very difficult because that something would have been taking the space (IF3)

The others were either unsure or suggested that the spaces between particles were occupied by air or water vapour.

I: You talk about the spaces between the particles, is there anything in the spaces between the particles?
S: ...Other gases...water vapours...water vapour, yes water vapour and sometimes other gases (IF4)

6.2.2.9 Activity 2 The inverted glass submerged in water

This activity was intended to probe the students' perceptions of the gaseous phase, in particular to determine if they viewed this phase as having physical characteristics. Only three of the students made an incorrect prediction claiming that the cotton in the inverted glass would become wet when it was submerged. Of these one was simply guessing while the other two claimed that there was nothing in the glass, only air.

Of those who predicted correctly all claimed either that the air took up space or that it imparted pressure or force preventing the water from entering.

S: Because the pressure...the pressure is pushing...the air pressure inside the bottle has caused the cotton not to get wet.
I: Do you know what causes air pressure.
S: ...the water.
I: The water causes air pressure? How does the water cause air pressure?
S: The pressure from the water is from pushing inside and the air pressure is pushing down.
I: Pushing down on the water?
S: So it builds the surface there.
I: Do you know exactly what causes the air pressure?
S: I'm not sure (IF2)

I: Could you explain why that happened?
S: Because when you turn that (beaker) over, it is filled with air and that stops the air getting in.
I: Do you know how the air stops the water getting in?
S: No I couldn't say (FM1)

However, although ten students (3 Fijian and 7 Indian) used the concept of particles in their explanations, only five of these suggested the particles actually pushed against the water, and no one employed the concept of the particles colliding with the surface of the water and exerting pressure in this way.

> I: So why does the water not go straight through the air and touch the cotton?
> S: Because...the air particles are pushing the water downwards, and the water is trying to push upwards...there's pressure on both sides (IF6)

One student stated that the air created a vacuum which prevented the water from entering the glass, while another believed that it was the pressure from the hand pushing the glass which kept the cotton dry.

> S: This pressure (from the hand) is more than the pressure from the liquid...so the water cannot get inside (IM6)

6.2.2.10 Activity 3 The ball and ring

This activity was intended to probe the students' views on heating solids and expansion. In this instance all twenty four students correctly predicted that the metal ball would not fit through the ring after heating, and all were familiar with the concept of expansion. A total of twenty one students incorporated particles in their explanations (9 Fijian and 12 Indian) and expansion was generally explained by the heat acting on the particles and causing them to vibrate more or move apart.

> S: I think when you heat it the particles in the solid vibrate and they move around a bit causing the ball to enlarge (IF1)

> S: It won't get through the hoop because once it's heated the particles expand, once it's expanded it will get bigger in size and then it won't go inside.
> I: Again you've said expand, in this case do they get bigger themselves or move apart?
> S: They move apart, they won't get bigger, they move apart.
> I: And why do they move apart?
> S: Because it has accumulated more energy, due to that heat it tries to move apart (IF3)

The most common alternative conception (5 Fijian and 2 Indian) was the view that the particles did, in fact, grow in size, or alternately that they moved apart and grew in size simultaneously.

> I: What makes the ball expand?
> S: The particles inside because it's solid they expand.
> I: When you say expand do you mean the particles move apart or get bigger or do both?
> S: I think they get bigger and move apart (FM5)

Finally one student generated a novel alternative framework to explain expansion in metals when they are heated.

> S: Maybe some air particles in that solid ball tried to move out and therefore made the ball big...it pushed the solid a bit outward (FM1)

6.2.2.11 Activity 4 The air thermometer.

This activity, like card 7, was intended to explore the students' views on gas pressure and how it is affected by changes in temperature. However, unlike card 7 it was intended to offer the students a more substantive example of gaseous pressure increasing than that offered through a two dimensional medium. In this instance Indian students (8) were much more likely to use particles in their final explanations than Fijians (2).

> S: The air particles in here have gained heat energy and they want to move so it contacts with the water and the water moves out (IF3)

Nevertheless there was no difference between the two groups in terms of their initial predictions, with only four students from each group predicting correctly that the bead of water would rise when the flask was warmed using body heat. Most (8) predicted that the bead would drop down into the flask, while the remainder predicted it would not move or were unsure. Only one of these students could justify his prediction, which suggested a strong element of guessing among the students. However, upon completing the activity, most provided an explanation which incorporated the concept of increasing air pressure. Six of these related the increase to pressure transmitted through the glass from the hands, while the remainder attributed it to increased temperature as a result of body heat. For example student IF1's initial prediction was incorrect and she was not able to justify it, but after completing the activity her view changed.

> S: Once we put our hands around this flask, the air present inside tries to escape and once it tries to move up it takes the water with it and due to that upward pressure so that air that's inside the water droplet is pushed out...it helps the particles to move due to pressure...the heat energy, any sort of energy that helps the particles to move (IF1)

None of the students mentioned that this activity demonstrated the same phenomenon as card 7, though they were not specifically questioned about a connection.

6.2.2.12 Activity 5 The model lung

This activity was intended to probe the students' understanding of the relationship between gaseous pressure and volume. In total fifteen students correctly predicted that the balloon ('lung') would inflate when the plastic diaphragm was pulled down (10 Indian and 5 Fijian). Of these students, only six mentioned pressure in their explanations and only one related an increase in volume of a fixed mass of gas to a reduction in pressure and air moving as a result of differential pressure.

> I: Why did the balloon inflate?
> S: OK the answer for that would be that when you pull this you are making gas to come inside due to the space that will take some gas particles...so you're making gas particles lesser here so that will be catered for by gas from the outside...air from the outside.
> I: So what causes the air to come inside?
> S: A reduction in pressure inside.
> I: So if you reduce the pressure inside how does the air get in?
> S: Well the air moves from the higher pressure outside to the lower pressure inside (IM6)

Although five students mentioned particles in their answer none related pressure to particles colliding with the sides of a container. All of these students claimed they did not know how gas particles collectively produced pressure within a sealed container.

Seven students (3 Fijian and 4 Indian) believed that air was sucked or pulled into the balloons by the action of pulling down the diaphragm.

S: As soon as you pull that thing at the bottom, the air from the atmosphere is pulled inside (IF3)

One student having claimed that a vacuum was created in the balloon, when probed further stated that the force of gravity was the actual mechanism which drew the air into the balloon.

I: So why does the balloon inflate?
S: The air is...it creates a vacuum so the air has to...the air comes in to fill the vacuum...so that's how the air gets in...it's similar to the diaphragm in our lungs.
Later
I: But what actually causes the air to move into the balloon?
S: Gravitational pull...it's something like how low pressure so air rushes in to fill...that's how you get rain.
I: You mentioned gravitational pull...does that play a part?
S: I think it plays a part because that how the air moves down due to the pull of gravity which fills the vacuum, so the balloon inflated (IM5)

6.2.3 Summary

Clearly, in the domain of matter and how matter changes both Indian and Fijian students held many alternative conceptions which, in general, were largely similar. For example, the view that the bubbles in boiling water were formed from air, that the particles in a metal ball grow larger when heated, or that sugar melts before dissolving. Furthermore, the conceptions expressed by the students in Fiji proved to be very similar to many of those presented by the Australian students interviewed during the pilot study. This apparent commonality in conceptions amongst students from extremely diverse cultural backgrounds indicated that these alternate notions about changes in matter had no cultural root or origin, and must have derived from another source, possibly through instruction or interactions with the physical environment that were not culturally mediated in any way. In fact the students in Fiji, when asked if they could think of any traditional beliefs which ran counter to the teaching they had received on matter, were unable to recount any.

Although all of the Fiji students had been introduced to a particle model of matter during the compulsory Basic Science course undertaken at high school, for many this model was only partially remembered or appeared to have become 'hybridised' with their own intuitive ideas. As a result, understanding of various phenomena was often superficial and attempts to explain the underlying principles of these phenomena were in many cases confused or tentative. In fact students could provide no micro-level explanation for some of the phenomena.

Even those students who employed a well conceptualised molecular or particle model in explaining one particular instance rarely applied this consistently across the entire range of instances.

In general Indian students were more likely than Fijians to utilise a molecular model in their explanations. It also appeared from the CPIs that a greater prevalence of alternative conceptions existed amongst the Fijian participants in the study. The latter finding is reported in more detail in a later section which deals specifically with determining the prevalence of alternative conception in a much larger sample (n=143) of the college population.

6.2.4 Student teachers' traditional beliefs

The initial part of the interviews tended to indicate that the alternative conceptions students held about matter and how it changes did not derive from any cultural or traditional source. Furthermore, when conceptions not primarily encountered in either the literature or the pilot study did appear, they were not widespread and thus there was no evidence that they derived from a particular cultural worldview.

Having said this, it was of interest to see if the students could identify any traditional beliefs from their respective cultures which were in direct conflict with the scientific view and consequently this aspect was probed in the latter part of the interview.

The researcher found that asking general questions in this area such as 'Do you know of any traditional beliefs which are different from what you learnt in school science?' was not very fruitful and, in order to stimulate discussion, students had to be referred to specific beliefs. The Indian students who responded could be categorised roughly into those who accepted the traditional or cultural worldview, those who held a mixed view, and those who accepted the scientific view. This sort of categorisation was more difficult with Fijian students for reasons to be discussed later.

6.2.4.1 Indian students

The Indian population in Fiji is composed of approximately 80% Hindus and 20% Muslim. Both groups have, for the most part, maintained their traditional beliefs and values despite the growing influence of Western culture in Fiji, which is becoming more and more pervasive. Thus there are still many traditional beliefs which exist that are in direct conflict with the scientific concepts which students learn at school. For example, Indian Hindus hold a cultural worldview about the effects which a solar or lunar eclipse may have particularly in relation to food contamination and birth defects. This view asserts that food prepared before an eclipse and not eaten immediately will be bad by the end of the eclipse. Furthermore, pregnant women who use knives to cut food during an eclipse are likely to produce children with birth abnormalities. These traditional views are clearly at odds with the scientific view. However, a number of the students (4) held to these traditional views.

> I: There's a Hindu belief or an Indian belief that during an eclipse of the sun you shouldn't eat the food that's prepared...because...
> S: They call it Grahan.
> I: Is that what it's called?
> S: Yes especially with the pregnant mothers like that thing happen.
> I: And you believe this or you think it's not true? I mean if there was an eclipse would you eat the food?
> S: No.
> I: Do you believe that something...that you would become sick?
> S: Yeah it has happened eh to one of my family members...that thing has happened and the mother was not aware of that one...so what has happened, as soon as that thing was on the mother took the small knife and she was chopping the onion or potatoes...something and when child was born and he was a boy and he was missing with three fingers (IM3)

> I: You know the Hindu belief about eclipse of the sun and the moon that you shouldn't...if you're pregnant you shouldn't cut...
> S: Cut anything...that's true.
> I: You believe this one?
> S: Yes eh, why I believe because one of my uncle is just having three small fingers and then I learn from my grandmother that eh she told us that it happens when especially when the ladies are pregnant and they cut something or do something which they are not supposed to do, then some abnormalities will develop in their child...and result of that is one of my uncle he just have three of his fingers.

I: You don't think there could be another reason why?
S: There may be but I can't think of any.
I: So if you become pregnant and there's an eclipse would you cut anything.
S: I won't.
I: Definitely not?
S: Yes
Later
I: And what about during the eclipse you shouldn't prepare food?
S: Yeah it was a belief but at the moment some people are not following that...like just last Dhwali it was a moon...sun eclipse I think and then we were not supposed to eat those things which we had prepared but then we ate all.
I: And what happened?
S: We can't say what will be the result of it, it may be one year or two years in the future.
I: But you think something bad will happen?
S: Yeah something bad will happen (IF6)

Most Indian students (8) rejected the theory of evolution in favour of reincarnation (Hindus) or creation (Muslims). However, none of those interviewed indicated that they objected to learning about this theory even though it was at odds with their own beliefs, and a number stated that they found the study of evolution very interesting.

I: What about Form 7 Biology, you learnt about evolution?
S: That we originated from monkeys and all that?
I: What does the Hindu culture tell you?
S: So from our religion, Hindu religion side, we...it doesn't tell us that. We believe in our Ramayan, cultural holy book...we believe in that, we don't believe in evolution.
I: But do mind studying it.
S: Yeah we don't mind.
I: Why is that?
S: Because we are so bound to our religious...
I: So it doesn't change your view?
S: Yes, even though there might be strong evidence from science, but if we follow our religious system, we don't believe in the science, they are different (IF4)

Furthermore, when asked about a local religious icon, the Naag Mandhir or snake god (a rock formation which is alleged to be growing and strongly resembles the hooded head of a cobra), most Hindu students (8) viewed it as a magical rather than a geological phenomenon.

I: You know the Cobra in Labasa?
S: Yes, the Naag.

I: Do you think it is a magical thing or is there say a geological explanation?
S: I think it's a magical thing from God's power.
I: If someone told you it was formed by volcanic activity, what would you say?
S: I wouldn't believe that (IF4)

I: If the person said I want you to test that...to do some experiments on the Naag, to measure and record and observe and so forth...
S: No it has happened like that I think 4 or 5 years before. Most of the people especially Fijians they didn't believe that eh it was a religious thing, they thought it was a science made thing so they wanted to test, so they did some wrong thing there and they were affected with a lot of sickness and one of them was dead (IM3)

At the other extreme, some Indian students (4) either generally accepted the scientific view in favour of traditional views or felt that many of the traditional beliefs had scientific explanations.

I: There's a Hindu belief that during an eclipse of the sun if you are preparing the food...
S: Yeah like you have to eat it before the eclipse or you throw it.
I: What are your views about these things?
S: No I don't believe them...there was an eclipse last year and according to my horoscope...in our culture we call it Kumbhraashi...it is bad for me to go outside or watch the eclipse...so it was over the radio so my mother told me I have to stay in the house all day because the sun's rays will harm me, like I'll get sick or something more dangerous.
I: So what happened?
S: Nothing...my mother didn't allow me to go outside so I had to stay inside.
I: Would you have gone outside if your mother hadn't...
S: Yes because I don't think it's true. Like eclipse happens when the earth and moon and the sun comes in line...so its just a coincidence that eclipse happens, so that's the scientific...but in our belief...we had to stay inside (laughs).
I: And so obviously your mother...your mother obviously believes.
S: Yes but actually another eclipse happened that was in the moon, my mother didn't ...she told me not to watch it but I watched it through the window but nothing happened.
I: You saw the moon disappear
S: The moon becomes red...but nothing happened...nothing (IM5)

I: You mentioned before that there are Indian myths and stories, but it was good that science gave the real facts. Can you think of anything in science which is different from the myths and stories you get from your elders.
S: Yes like...but some of them they have got the scientific belief, like they have myths but they did not use the right way to explain. When looking at the story you can find some good things. For example, I don't know many but one I just know is the Indians believe that you should not sweep the house at night time it's bad. But they never explain to us, but when I look at this scientifically it explains that the Indians they usually had mud floors

rather than concrete so previously they had mud floors so when they sweeped the particles of dust which is bad when you inhale it remains in the room and the windows is normally closed during night time so when you sleep the particles, can you can inhale the particles. Scientifically that is good but when looking at Indian culture they have not explained they just told it's bad and you have to accept it (IF5)

These students demonstrated an appropriation of the scientific worldview by indicating that they generally found science enlightening as it provided a connection between the cause and effect of many phenomena. This they claimed was something which many traditional beliefs could not offer. For them this also removed the element of fear associated with many traditional beliefs.

I: If you understand the scientific principle of an eclipse, do you find that beneficial?
S: Very beneficial...because now I know that the eclipse cannot harm me (IM5)

Other students (2) seemed to adopt an eclectic approach and hold both scientific and traditional views simultaneously, switching from one to the other when appropriate.

S: Eclipse...according to science that thing happens when planets come in line.
I: Right.
S: But our belief is that eh you know one of our mini gods Hanuman causes an eclipse.
I: So which view do you believe, the science one or the Hindu one?
S: Well I believe both.
I: How can you believe both?
S: Well see I'm quite a religious fellow, but I believe in science also...science tells me that eclipse occurs because of the aligning of the sun, moon and the earth...well there's that theory part of it and eh and my culture tells me a different way that that thing happened and I just believe it...I have to believe it because I live with my society, my family, if I go against them...if I don't agree them...at times I don't agree with them but sometimes I have to (IM6)

However, none of the Indian students claimed to be completely unaffected by their cultural roots. Even subject IM5 who rejected the Hindu worldview of an eclipse and seemed to genuinely accept the scientific explanation claimed he still held certain fears which derived from his cultural upbringing.

I: Would you be frightened to do some experimental things to the Naag?
S: Yeah I will, I will.

> I: Why is that?
> S: I mean even though there's a lot of scientific explanations or you know from science that nothing will happen, but you have been brought up in a Hindu family, there's something inside me tells me: no it will harm you (IM5)

Regardless of how firmly students held to their traditional beliefs, they claimed that these in no way interfered with their learning of science. They appeared to be able to contextualise their knowledge with the traditional meaning of a concept being applied only in a traditional setting and the Western meaning being applied in contexts where it was appropriate such as the science classroom. Thus when a group of Hindu students was later asked if they would include reference to a solar eclipse in response to an examination question on food spoilage, their reply was unequivocal.

> I: Say you get a question in an exam about food spoiling, would you write about the eclipse?
> Ss: No we'll have to take the science point of view...mention bacteria and things like that.

However, when asked which view they actually adhered to themselves, they seemed to find the question difficult.

> I: But which do you believe the science view or the traditional view?
> Ss: Whilst in school we have to do with science because we have to do an exam paper, but at home when we talk we have to say the traditional views.
> I Yes I understand that you have to in some situations say one thing and in another situation say something else...but what would be your own personal view?
> Ss:..
> I: Do you not really think about that?
> Ss: We have some limitations as well...if we talk too much about science at home especially the Indians, sometimes it is not accepted...because the Indians are, especially in rural areas, too much towards the traditional views, very less of the science.

6.2.4.2 Fijian students

Probing the traditional views of Fijian students proved to be more problematic. There were two reasons for this. Firstly, although many of the students had been born in rural villages, most had subsequently been brought up in urban areas where they were less likely to be exposed to traditional views, in fact three Fijian students interviewed could recollect no traditional beliefs from their culture. Secondly, because most of the Fijians held quite fundamental Christian beliefs, some had rejected many of the traditional ways of thinking which they viewed as evil. Nevertheless a number of the students interviewed, particularly those who regularly returned to their villages, appeared to encounter problems reconciling the traditional views expressed there with their Christian beliefs and their school science. Many of the traditional beliefs related to witchcraft and black magic and some students claimed to have experienced this first hand.

> I: What is that called? Is there a name for it in Fijian?
> S: Yes, Vakatevoro.
> I: And what does that actually mean?
> S: It's a form of witchcraft to make that person die.
> I: Die! So do you yourself believe this works?
> S: Yes
> I: Have you experience of it?
> S: Yes
> I: How come?
> S: My sister died.
> I: She died?
> S: In '93 because of that.
> I: How do you know it was from that?
> S: They were performing in our village some men, there were 8 of them, they were performing that kind of thing.
> I: And what happened to your sister?
> S: Died...she got sick.
> I: How old was she?
> S: Fourteen.
> I: Why would they want to do this?
> S: Because my father...they had a fight that's why?
> I: With the people in the village?
> S: Yes it's always like that...one year ten of them died...last year.
> I: Because of...
> S: Yeah...they perform something...dance and presenting yagona to the devil.
> I: So you think they can get the devil to do something bad?
> S: Yes (FF6)

Another student who claimed to have experienced a similar event spoke about how he reconciled this with other views.

S: Yes I've seen it (someone die through Vakatevoro)...I mean I believe...I partly believe in that, but often when I mean we are growing up in a time when there are lots of ideas and people talk about why things happen...scientists and doctors and we have our own beliefs and we go to school and our teachers tell us about something else and that clashes and we just pick which one we accept.
I: So do you actually make a conscious decision as to whether you will accept the scientific view or the traditional view?
S: No I'll just put it to situations...sometimes with the scientists and sometimes with the (village) elders.
I: So depending on the situation you might choose one view or another?
S: Yes (FM1)

The same student related a further situation where a traditional view appeared to be in conflict with the scientific view.

I: Are there any traditional beliefs in Fijian culture that you might hold that you have found to be different from what you learnt in school science?
S: ...beliefs? Oh yeah...an example is the coming of a hurricane. Our traditional beliefs...I mean our elders believe that when they see hornets nesting below tree level or they see breadfruit blooming...I mean three or four fruits on one branch, they believe that a hurricane is coming, and in science we know that hurricanes come when there is something to do with air pressure or something.
I: So which view do you accept the view of the elders or the view of the scientists?
S: Both 'cause, I've seen both.
I: So you've experienced the first one and it was correct?
S: Yes it was correct...but with science maybe because I...I'm not sure what happens when air pressure changes or what I'm not really...I'm not in favour of that, I mean not completely in favour of the idea.
I: Of the scientific idea?
S: Yes.
I: Is that because you don't fully understand it or you think it's not true?
S: I don't fully understand it and secondly you know, see when I see something I believe that, maybe that's caused because that happens (FM1)

This student may have been confusing an effect of the hurricane (i.e., hornets nesting low down) with the causative factors, but for him this distinction was not important, and there was clearly some conflict between the two views. However, in some instances religious views appeared to take precedence over traditional or scientific views.

I: If you got sick would you ever visit Vakadraurau?
S: No I never visit witch doctors...when it comes to these things I always believe on my Christian beliefs.
I: So are you saying that when you have a choice between a traditional belief and a scientific belief, you may select one or the other, but if there is a

clash between traditional and Christian views you will generally go with the Christian view?
S: Yes I take my faith very seriously so I'll reject it (the traditional view)...put it aside (FM1)

I: If you saw a rainbow in the sky, would you say that had a scientific explanation or was a magical thing.
S: No I wouldn't say it has a scientific explanation...because just like I said, I'm a very religious person so I think that was the sign, you know, when there was a flood and then God said...you know...
I: What about some of these things you saw today like the balloon expanding?
S: That's scientific.
I: So you think there is a definite scientific explanation for why a balloon expands, but a rainbow...
S: That's different, that's Biblical (FF3)

Certainly none of the Fijians interviewed accepted the theory of evolution, all of them claiming to be creationists, although only two students objected to having to learn about it.

However, as with the Indian students some Fijians (3) generally accepted the scientific view over the traditional views.

I: Do you think that all things can be explained scientifically, or do you think that there are things that are just sort of magical, that can't really be explained by science.
S: They can be explained by science.
I: What about older people in your society, do older people believe the same thing or do they see some things...
S: They see things differently
I: So your view is different from theirs, is that because of your education.
S: Yes
I: Do you think a rainbow can be explained scientifically?
S: Yes.
I: Do you know how it forms?
S: It's light...light and water.
I: That's about right.
I: So the change in attitude in Fijian society about challenging your elders, do you think that's good?
S: Yes I think it's good (FM4)

S: Traditional beliefs....especially the owl eh when it hoots in the night they believe that someone's getting pregnant in the village...but for my...from what I think that's totally ridiculous.
I: Why do you think that's ridiculous?
S: Since I'm able...I'm educated and I know the reason behind it to prove that it's wrong. Because I think that when the owl hoots in the night it's sort

of eh there are probably two reason behind it. One probably mating season or for the guard of it's boundary.
I: For territory?
S: Territory, like to mark it's territory it hoots around a bit like the dogs when they guard their territory, it's like that.
I: So you would say there's a scientific reason for the owl hooting, it's not a supernatural thing.
S: No
I: So you don't think there's a connection between the owl hooting and someone getting pregnant?
S: No...not even any...I think that was a myth and they sort of tried to brain storm people to believe that...so in past generations they believed in it but now we can prove it wrong since we have evidence or facts to support our ideas.
I: So you've rejected some of the traditional beliefs.
S: Yeah.
I: Because you've accepted the scientific ideas?
S: Yes.
I: What about your grandparents how do they view such things as the owl?
S They really believe in it and eh they sort of...all aspects of our tradition they hold it very important (FM6)

Thus it appeared that Fijian students often experienced conflict between the Western scientific view and either religious or traditional beliefs. In some instances this conflict may have been even more complex with tension between all three ways of viewing phenomena. However, as with the Indian students the Fijians appeared to be able to contextualise these different views, selecting whichever was appropriate for a particular situation.

6.2.5 Summary

It is difficult to explain why, amongst these students, one domain of science, in this case matter, appears to offer little potential for conflict with traditional beliefs, while for other domains there are clearly conflicting viewpoints which could result in confusion for the learner. Perhaps much of physical science comprises domains of knowledge which are sufficiently abstract such that traditional cultures have never developed an alternative belief system of their own, resulting in a lack of interference between these domains. Thus the alternative conceptions which do arise may be instructionally derived, as school is the only exposure students get to these aspects of science. This would help explain the consistency of alternative conceptions across three different cultures in this study and the pilot study in Australia.

However, in less abstract areas of science such as issues of health, which individuals are likely to encounter on a regular basis, alternate belief systems develop much more readily in traditional societies, and often these do conflict with the accepted scientific view.

These findings clearly have implications for the teaching of science in Fiji and other traditional societies and this will be discussed in more detail in the final chapter.

6.2.6 Student teachers' views on the nature of science

Since some of the students were to be exposed to a series of innovative teaching strategies as part of a teaching experiment, it seemed appropriate to obtain some of their views about the nature of science and how it should be taught. Thus, as part of the elicitation phase, these views were also sought.

According to Lederman (1992) there appears to be strong agreement, even between different countries, on at least one of the objectives of science instruction. The development of an 'adequate understanding of the nature of science' or an understanding of 'science as a way of knowing' continues to be convincingly advocated as a desired outcome of science instruction. This is true for the science curriculum in Fiji, where the Basic Science course is designed to:

> Develop an awareness that scientific knowledge is tentative, subject to change as evidence accumulates, that science has its limitation and cannot explain all phenomena or solve all problems (Fiji Ministry of Education, 1981 p.4).

Certainly the view that science is 'a way of knowing' was not one shared by the students. Having said this, only one of the students interviewed regarded science as a body of knowledge composed of indisputable facts. In so doing, she presented this notion of science as a contrast to the traditional views of her own society.

> I: If you were asked to explain to a friend what's meant by science, what would you tell them?
> S: Well science, from my point of view it's based more upon reasoning, it's a factual...you'll find facts and eh reasons to the answer rather than comparing to like some of the things like myths and religion...em...myths and stories, but here in science you have definite answers and you have reasoning over there.

I: So compared with myths and stories science has got definite answers?
S: Yes, definite answers (IF5)

Many other students viewed science as a study of the environment or living and non-living things (14). It transpired that this latter notion was a definition provided in the students' Class 7 science text, and although some students had trouble expanding on this, others indicated that science was about experimentation, discovery and invention. These views were common to both Indian and Fijian students.

I: If you had to explain what science was to a friend what would you say?
S: Science is the study of living and non living things.
I: When do you learn this, that science is the study of living and non living things?
S: Class 7
I: That's from the book yeah?
S: Straight from the book
I: If I put it another way and asked you what do scientist do?
S: That's in the lab you mean?
I: Whatever you think a scientist does that's what I want to hear about.
S: A scientist is supposed to carry out experiments...he's supposed to find out about why things happen and this and that...why things happen, what causes them to happen. Well he's supposed to find out like this and the job of a scientist is to come up with new things...if you go in the direction that we have new things now new developed things...that's technology...and improving things that what scientists do (IM6)

One student questioned the definition of science he had been presented with in school, suggesting that science offered a way to explain things.

I: Just to get your views on science...if I asked you to explain to a friend what is the nature of science or what is the meaning of science, what would you say?
S: The meaning of science?
I: Yes, to you
S: I mean science is, as I was taught in Class 7, is the study of living and non living things. But I think science is eh that's I mean more basic...science is the study of the nature how it affects us and how we affect the nature...for example for a small child if you tell him...if you throw a stone up it will come down. The child knows because he has seen but he doesn't know why it has happened so it is important to...for example, him to know that's why a mango from the tree falls down why not up...it is very important you have to know the basic concepts.
I: So are you saying that science is something that offers explanations.
S: Yeah very much explanations...I mean like people believe many things but when you scientifically prove it...for example people say the sun rises and sun sets...it doesn't happen, the sun is always there but due to the earth's rotation that's how we see it (IM5)

Only three students (2 Fijian and 1 Indian) incorporated the notion of theory or hypothesis into their notion of science.

> I: And if you had to explain to a class what a scientist does, or what scientists do. What would you tell them?
> S: I'd tell them that science mainly involve a lot of activities, like doing science you ...that's what the scientist they do...like you just answer questions...like you write down a question that is your....what is that word?
> I: Hypothesis?
> S: Yes hypothesis...you write one hypothesis, and from that hypothesis you form your own activity then the result of that activity will solve your hypothesis (FM3)

When asked about scientific proof most students revealed strongly positivist views. Sixteen students believed that scientists could prove things to be true.

> I: And do you think that scientists can prove things to be true?
> S: Yes they do experiments and they tend to prove things to be true and give scientific reasons.
> I: Can you think of one thing that scientists have proved to be true?
> S: About the reasons they give for thunder and lightening...it's quite different from what our parents told us. 'Til I was in primary school I used to believe that the thunder is because the God is rolling big stones in the sky, but at school I came to know that it's due...some scientific process, but I can't remember (IF1)

However, a number of students (4) seemed to confuse the idea of scientific proof with scientific achievement.

> I: Do you think scientists can prove things to be true?
> S: They can prove.
> I: They can?
> S: They have proved.
> I: What sort of things have they proven?
> S: They have proved...they have found out all of the cures for diseases and other things they have found out.
> I: What other things have they proven?
> S: They have reached the moon (IM1)

While some students claimed they were not sure if scientists could prove things and others felt they could only prove some things, one Muslim student provided what appeared to approach a relativist view of scientific proof.

> I: Can scientists prove things to be true?
> S:...somehow it could be true, but it depends upon the people as how they take it whether it's true to them or not. It may be true to the scientist but it's upon the people to believe it.

Later
I: Just to go back to that question about scientists proving things to be true, do you think they can make laws that will always hold...will always be true?
S: Up 'til now there have been many laws that we carry out but how far it is true, we don't know (IM3)

All of the students interviewed believed that it was important to learn science at school and felt it was relevant or at least partly relevant to their everyday lives. Two Indian students reiterated the view that science explained things which their traditional beliefs could not. However, for most (16) relevance related to producing a better understanding of the environment in which they lived and consequently a knowledge of how best to utilise resources. Perhaps surprisingly only one student referred to issues of health, while another related school science to the technological changes taking place around him.

I: And do you think it's important to study science at school?
S: Yeah, it's really important especially now a days with the modern technology and...em I think it's a must that we should study science...because everything involves science and in order to adapt to this fast changing world we have to be critical about the things around you (FM6)

More than half of the Fijian students believed that only individuals of above average ability could do well in science as it was perceived as a particularly difficult subject. However, the majority of Indian students (13) argued that anyone could do well as performance was more closely related to interest than ability.

6.2.7 Students' views on the learning environment in science

The students were also asked to give their views on the teaching and learning of science. These were probed by asking students about the role of the teacher when conducting science lessons and obtaining their ideas on a number of other issues such as the use of questioning in lessons, co-operative and competitive classrooms and the examination system in Fiji. This was intended to elicit the students' views about their preferred learning environment rather than that which they actually experienced during their own schooling.

Students from both Indian and Fijian cultures shared a number of common views on the learning environment. Most students (21) felt that a didactic mode of science teaching in which the teacher employed an expository approach, was inappropriate, and science should involve a major practical component where the students were actively involved in discovering things for themselves.

> I: When you think about teaching science, is it a good idea for the teacher to stand up and tell the children everything?
> S: I don't think so...they have to make things for themselves...to find things out for themselves...whether it is true or not...whether the experiment is successful or not (FM5)

In general, the students (18) also saw the teacher's role as one of a facilitator rather than a director of science activities.

> I: What are your feelings about how the teacher should conduct a science lesson? I mean do you think the teacher should be like a policeman controlling everything, or do you have a different view of how science should be taught?
> S: Science in school should be activity-based where the children are involved in the activity, because that would give them the chance to actually participate and see for themselves what is actually taking place rather the teacher telling. Because we believe that whatever children do and see themselves they tend to remember for a longer period of time compared to what they are told.
> I: Do you think the teacher should demonstrate activities first before the children carry them out?
> S: The teacher should guide the children if necessary, but not demonstrate, because if the teacher has already demonstrated to them, then the children then the children won't take that interest to do the activity for themselves because they've already seen what was taking place (IF1)

> I: The teacher...do you think a science teacher, should they be like a policeman, controlling everything...how do you think the teacher should behave?
> S: No they should be more like a guide and help the children to do the experiment on their own...(IM3)

However, this view was not shared by all of those interviewed, a number of students viewing the teacher's role in practical science as more directive.

> S: The teacher should be active and should tell the children what actually had to be done step by step, and should show the experiment to them. The teacher should first do the experiment, show it to the class and then let the class do the experiment.
> I: Why do you think the teacher should show the class the experiment first?
> S: Because the children don't really know what to do so they can follow the steps easily (IM1)

All of the students felt that the use of questioning was particularly appropriate in science instruction.

> S: Once the teacher asks the question to the children it should not be just a yes or no answer question. It should be a question in a form were the children have to give their views, their reasoning and not just yes no.
> I: Do you think the questioning should be both ways?
> S: It should be both ways...then the teaching and learning would be more effective (IF1)

In commenting about the use of questioning one student expressed views which were very similar to aspects of a constructivist view of learning even though he had never been introduced to this model.

> I: Do you think it's good for the teacher in a science lesson to ask questions?
> S: I think it's good to for the teachers when they conduct their science lessons to listen to the views of the children...first of all how they think, what they think is going to happen and what has happened and why (FM1)

Perhaps one of the most interesting aspects of the students' thinking on the learning environment was their universal belief that it was appropriate for students to challenge the views of the teacher. This was unexpected, as for both Fijians and Indians, it is considered culturally taboo to question the statements of elders. However, the students argued that the school and village environments were quite different, and also claimed that their own societies were slowly changing to accommodate more critical attitudes.

> I: Do you feel that it is OK to challenge the ideas of the teacher?
> S: I mean provided the student is able to prove what the teacher is saying is wrong, I mean not always the teachers are correct too.
> I: What about in your culture...is it OK to challenge your elders?
> S: No it's not.
> I: So why is it different in the classroom because the teacher will be your elder?
> S:...maybe because the home situation or village situation is different...we are not given those classroom teachings and other things...but in school we are learning something extra apart from what we have learnt in the village, so the feeling is there that whatever we are learning it should be correct (IF6)

> I: If the teacher says something which you don't agree with do you think it is OK to challenge views of the teacher?
> S: Yes I think that's OK.
> I: What about challenging your elders?

S: Oh in our culture...that's different...if elders say something you have to follow even if...you can't challenge them.
I: But you see school as different?
S: Schooling is different. Take for example if the teacher is eh talking about something and you think that he or she is not true, you can stand up and say...as long as you've got some evidence (FM5)

One Fijian student commented that parents were becoming more educated and thus encouraging their children to ask more questions. However another Fijian said that, although she felt that it was appropriate to challenge the views of the teacher on some occasions, overall it was unlikely to happen in Fijian society because, in most cases, the students believed that whatever the teacher said was correct. In fact only one of the students interviewed claimed to have questioned what a teacher had said.

All but two of the Indian students felt that a competitive atmosphere was desirable in the science classroom. Competition between students was viewed as healthy because it increased motivation.

I: Would you think it was good to have a competitive spirit in the classroom...a competitive atmosphere.
S: Em...
I: Do you know what I mean by that?
S: Yes, competition in the classroom.
I: Well a competitive atmosphere.
S: Yes I think it's good.
I: Why do you think that it's good.
S: I think a competitive atmosphere...it motivates the children towards achieving things faster and they know better about things...they are all the time aware of what they are doing, they are not lazy (IM4)

S: Yes we should create such an atmosphere where the students are very competitive amongst themselves because that would make the students work harder and then it would be...the teacher himself or herself would be proud to see the end result, because if everybody is competitive they will work hard and the end result will be excellent.
I: Are you suggesting that it motivates students?
S: Yes it motivates students (IF1)

S: A classroom where there is a lot of competition, I think that's a good classroom because it'll add or it'll give some sense of spirit of competition they will be eager to stand up for themselves and see who is first, who'll come top of the class (FM5)

One Fijian female student thought that motivation came from a more negative aspect of competition.

I: So you think competition is good for motivation?
S: Yeah.
I: Why do you think that?
S: Because you don't want to be the one at the back.
I: You mean the bottom of the class?
S: Yes (FF3)

This notion of competition motivating generally carried over into the students' views of the examination system in Fiji with 19 regarding the current system as desirable.

I: You know that there are a lot of national exams in Fiji, do you think it's good to have those exams?
S: Yes I think it's good.
I: Why do you think those exams are good?
S: Because it will make them (the students) reach out for more...for their education (FM3)

I And the exams in Fiji, here you have a lot of national exams, how do you feel about the exam system?
S: That is a good thing because through examinations we are able to assess the children and the teacher as well. It's not only assessment of the children but the assessment of the teacher, she would find out for herself how effective her teaching was (IF1)

One student thought that there were not enough national examinations and decried the abolition of the Form 5 (Year 11) national examination.

S: Those exams...I feel all the exams are good, but only if they can install the Form 5 exam again. They should still have that form 5 exam.
I: Why do you think the exams are a good thing?
S: There are other good ways, but still here in Fiji, only examinations can tell whether you are a bright student (FM2)

However, the conception that examinations were beneficial was not universally shared. Four Indian students and one Fijian were clearly aware of the potentially damaging effects Fiji's examination system could have on teaching practices.

I: You know there are a lot of national exams in Fiji, what do you think about that?
S: I feel that's too much...just too much because speaking from the teachers' point of view...if they get an exam class they just drill on the students. Here they teach us art, and craft and PE, even music, none of that is in the schools. I can say that because I've been through teaching practice and I've seen them how they do things like that...there is nothing of that just the exam subjects...they just drill you, drill you so the children they don't have any moral enrichment, the don't get much in music, they don't have their artist development...what they get is just cramming, cramming, rote

learning...there are so many exams to do, five of them, that's too much (IM6)

Despite the general perception that competition was a good thing in the classroom, all but one Fijian student believed group work was a good thing.

I: And what about students working in groups?
S: I'm in favour of that.
I: Why do you favour that?
S: Because if one person is working alone he won't come up with so many suggestions. If different minds work together then they will come with suggestions as to why it is happening or how to do it and what to do and what not to do (IM3)

I: What do you think about students working in groups?
S: It's good.
I: Why do you think it's good?
S: Because they'll all get to share their ideas and when they work in groups it's more effective (FF3)

When it was pointed out to students that there was a conflict between their views on a competitive classroom and the use of group work a number were confused and could not resolve this. However, others believed that these two notions were not incompatible.

S: I think it's possible to work in groups and still compete.
I: How is that?
S: Yes we did that in school we were competing against other groups...whenever we did experiments in science we were eager to know our results first (IM3)

One Fijian student related the use of group work in the learning environment to his cultural background.

I: Do you like the idea of group work or not?
S: I think so.
I: Why is that?
S: Like in England...the children are working in groups, so they've gone away from that old schooling system where...like we are doing now in Fiji here...in Fiji where we just learn things by ourselves.
I: Is that a problem?
S: In Fiji, in our Fijian culture we did things in groups so that's why we find it difficult for us to, you know, compete with the Indians here.. Because most of the time you see the Indians are on top and us at the bottom...the Fijians...that is the reasons...because we Fijians, we can't work well individually, we always work in groups (FM4)

However, this was the only student to make an explicit connection between pedagogy and culture.

6.2.8 Summary

Although few students viewed science as a body of knowledge made up of irrefutable facts, they still held strongly positivist views about scientific proof, despite the course objective regarding the nature of science. In general, the students presented ideas about the learning environment which appeared to be a mixture of the preferred environment and the actual environment. Clearly there was a combination of relatively innovative and strongly traditional thinking. While on one hand most students advocated the use of questions and group work in teaching, competition and a rigid regime of examinations were also favoured by many. These students had been introduced to a certain amount of theory on the teaching of science in their first year which promoted some of the more innovative ideas and this may have been appealing in its logic. Nevertheless, most of the students had also succeeded in a highly individualistic and competitive system where they encountered many national summative examinations. To some extent these differing experiences may have produced the dichotomous views about the learning environment which were expressed. However, the fact that these students appeared to be receptive to strategies such as group work and the use of questioning which are rarely employed in many Fiji schools, suggested that they might respond favourably to the types of teaching strategies proposed for the experimental treatment.

6.3 The prevalence phase

The main purpose of the Science Concept Survey instrument (SCS) was to ascertain to what extent conceptions identified amongst the interviewees and classified in the CPIs were more generally held in the larger population of the college. In particular it was of interest to compare the relative prevalence of these conceptions in a larger sample of each ethnic group. The SCS also acted as the pre- and post-test for the teaching experiment. The design and construction of the instrument (shown in Appendix A) has already been discussed in chapter 3.

6.3.1 Validation of the Science Concept Survey

The internal validity of the SCS was enhanced by using statements based on those made by the students, and by conducting a pilot run with first year students to check that the meanings derived by the students from the statements were those intended by the researcher. Further validation was undertaken by a panel of judges. In this instance six judges were asked to validate the survey items in terms of the CPIs. Once again the judges were selected for their knowledge of the subject and their experience of teaching science in Fiji. As it was difficult to find an entirely new panel of judges for this task from that used to validate the interviews, three of the six judges were the same. Once again, the panel was made up of graduate science teachers, university lecturers, or teacher educators. Table 6.10 provides information on the judges' backgrounds.

Table 6.10.

The Background of the Judges used in the Validation of the Survey Instrument

Judge	Background
J 1*	Lecturer in science education with extensive experience teaching biology and Basic Science at Fiji high schools (Fijian).
J 2	Senior lecturer in science education and head of department. Former high school chemistry teacher and principal (Indian).
J 3*	Lecturer in physics at the University of the South Pacific who had conducted a considerable number of in-service workshops with Fiji teachers (European).
J 4	Teacher of chemistry at a local high school in Lautoka (Indian).
J 5	Lecturer in chemistry at the University of Waikato. Formerly lecturer in chemistry at the University of the South Pacific (European).
J 6*	Teacher of biology and chemistry at a local high school in Lautoka (Indian).

Note: *denotes judges who took part in the validation of the interviews.

The judges were provided with copies of the survey instrument and the CPIs and asked to match the item statements to the statements in the CPIs. As with the previous validation, the judges were provided with the expanded CPIs which contained all of the statements made by the students in each sub-category. The researcher completed the same task and the results were compared.

The judges were also asked to comment on the clarity of the items and mark any which they felt were in any way confusing or ambiguous. Table 6.11 shows the outcome of the validation process.

Table 6.11.

The Percentage Agreement of the Judges with the Researcher on the Matching of Statements in the Survey with those in the CPIs.

Judge	Percentage agreement with researcher
J1	90
J2	94
J3	78
J4	88
J5	92
J6	92

The average agreement of 89% was considered to be satisfactory to proceed with the prevalence phase and administer the survey instrument. However, in the case of a number of items where more than one judge disagreed with the researcher these were discussed with the judges in an attempt to resolve the difference. For example, all of the judges disagreed with the researcher's coding for item 16, while four were also in disagreement with the coding for item 19. In the first instance the judges proved to be correct. The item had been incorrectly classified as B.2.1 by the researcher. This subcategory referred to physical rather than chemical change and had been misread by the researcher. The correct classification as suggested by the judges was B.2.4.

Item 19 had been constructed to investigate the students' views on the conservation of matter and, in particular, the belief that matter and energy are interchangeable. Having originally coded this item as B.2.4, the researcher reassessed the item and decided that it would be more appropriately coded as B.2.8, again in keeping with the majority view of the judges.

One item, number 32, which read 'During heating some of the acetone disappears because it has been absorbed by cork sealing the test tube', was thought to be confusing by the judges. The subsequent pilot of the test with first year students confirmed this and the wording was altered. However, overall, the survey was considered to be satisfactory by the judges, and as such it was first trialed and, after further minor revisions had been made, it was administered to the entire second year group.

6.3.2 Analysis of the survey data

The scoring of the SCS was completed by the researcher, with a single mark being allocated to each correct response. Although the items were true/false and designed to be objective, the addition of the free response meant that, occasionally, a subjective judgement was required by the researcher when a student made the correct true/false selection, but his/her free response indicated an alternative conception. For example, item 20 stated that 'The sugar crystals melted before they mixed with the water.' A total of 38 students selected false, which was the correct objective response, but went on to state that 'sugar melted *after* it mixed with the water', which in the view of the researcher revealed an alternative conception about the solubility of sugar in warm water. Such responses received no mark.

Since this aspect of the scoring was subjective, it required validation. To this end six judges, all of whom had taken part in previous validation exercises, were asked to score ten items taken across a range of six subjects, all of which required a subjective input. Their scoring of the items was then compared to that of the researcher. The outcome is shown in Table 6.12.

Only judge 6 disagreed with the researcher's scoring of the ten items and it transpired that this judge held the alternative conception which associated solubility with melting. Once the survey had been scored for all students, response frequencies were calculated for each item showing the number of students who held the scientific view, the number who held an alternate view and those who were not sure. This process was completed for both ethnic groups to allow the prevalence of conceptions between groups to be easily compared.

Table 6.12.

Judges Agreement with Researcher on the Scoring of 10 Selected Items from the Science Concept Survey

Student	S1		S2	S3			S4	S5	S6	
Item	15	17	22	15	20	37	37	16	14	20
Judge										
J1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
J2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
J3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
J4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
J5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
J6	✓	✓	✓	✓	✖	✓	✓	✓	✓	✖

Furthermore, all the alternative conceptions that appeared in the free response sections items were identified. Those which merely restated the item were deleted and the remainder were classified into categories of similar types (see Appendix H). This analysis provided a further mechanism for establishing the prevalence of various alternative conceptions, as it was possible to rank the conceptions in order to show their relative 'popularity' with both ethnic groups.

Once again, as this procedure was very subjective, two local science teachers (one Fijian and one Indian) were asked to classify the alternate responses to one of the survey items. Their classifications were then compared to that produced by the researcher. This showed that while the researcher had constructed five categories for the forty alternative conceptions identified, both of the judges had constructed six. Five categories were common to all three participants, while the extra category, constructed by the judges, contained a single conception which the researcher had clearly incorrectly classified. This agreement was considered to be sufficiently close to validate the analysis used.

6.3.3 Results of the prevalence phase

Before describing the results of this phase it should again be pointed out that there are certain potential weaknesses in using a survey instrument to diagnose alternative conceptions. Firstly, whereas an interview requires students to construct their own explanations, in the survey they were making decisions based on statements provided for them. In this situation, it is often easier to recognise the scientific view, as the statement can act as a stimulus to the long term memory (Rollnick, 1988). Conversely, as Bar and Travis (1991) cautioned, some of the statements provided can act as a source of alternative conceptions not previously held by students, particularly if they appear to be 'scientific.' There was certainly some evidence of the latter occurrence amongst the students in Fiji who completed the SCS as will be illustrated later in the discussion of item 50.

The data from the survey have been presented as response frequencies to each item rather than as total scores. Response frequencies are provided for both ethnic groups in Appendix A which shows the complete concept survey. The number of student responses are provided next to the options for each item, bold font denoting Indian responses and normal font denoting Fijian responses. The asterisk (*) indicates the 'correct response' to each item. The data have also been presented graphically as percentage values. Figures 6.1 and 6.2 display the comparative response frequencies of scientific conceptions (Figure 6.1) and alternative conceptions (Figure 6.2) for both ethnic groups across the complete range of items within the SCS. The comparative uncertainty of the two groups (i.e., the frequency with which the 'unsure' response was selected for each item) in their response to the survey items is shown in Figure 6.3.

In order to allow for a more detailed analysis of the data, the items pertaining to each of the five subcategories of the CPIs have been grouped together and presented graphically (Figures 6.4 to 6.8). The response frequencies for various individual items are discussed along with the qualitative justifications provided by the students.

6.3.4 General findings from the SCS

The general findings from this phase of the study were in keeping with those from the elicitation phase insofar as the survey revealed that overall the scientific view was more commonly held by Indian students while alternative conceptions were more prevalent amongst the Fijian students in the sample. As indicated in Figure 6.1, over

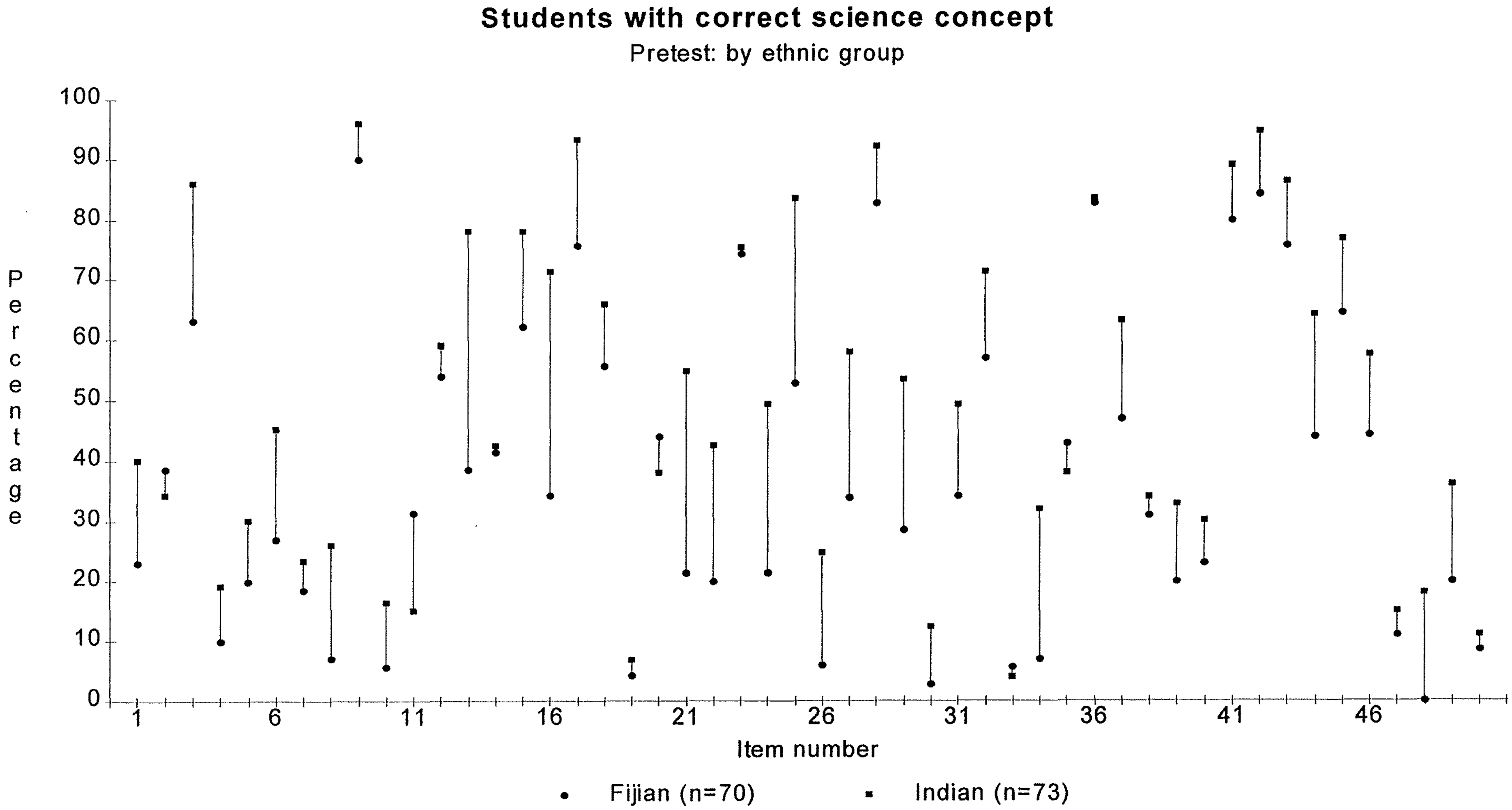


Figure 6.1. The percentage of Fijian and Indian students with the correct science concept.

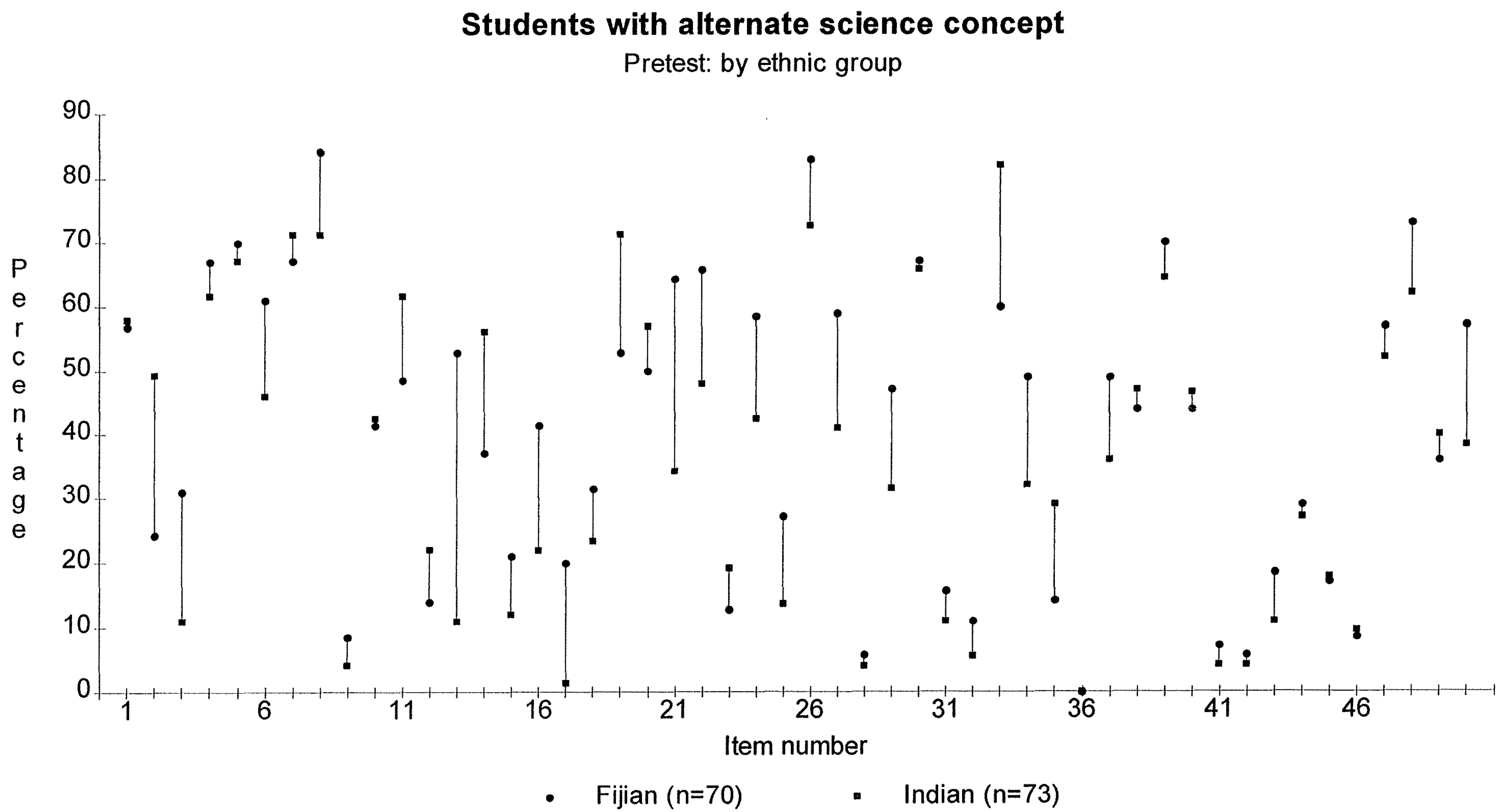


Figure 6.2. The percentage of Fijian and Indian students with the alternate science concept.

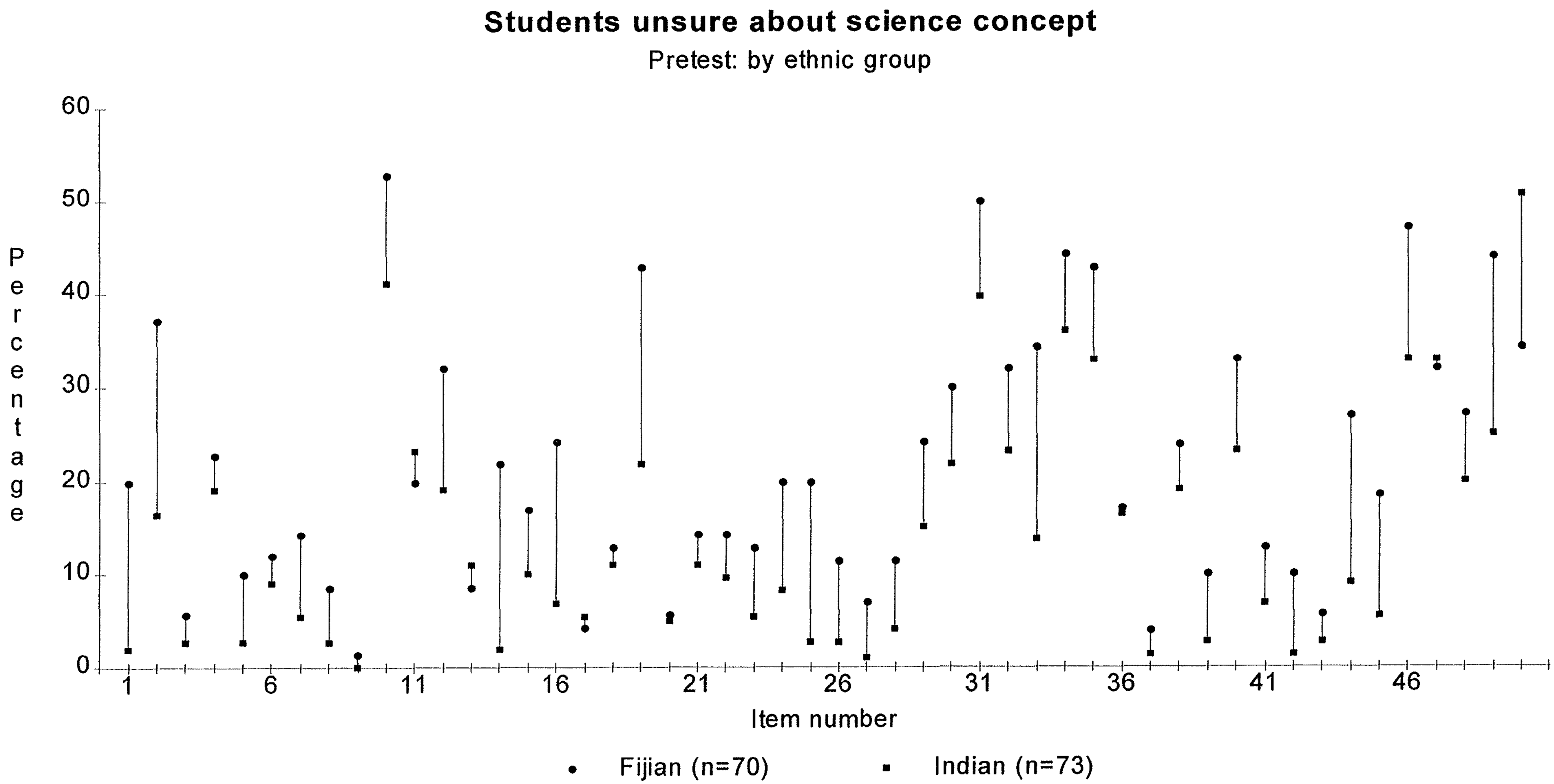


Figure 6.3. The percentage of Fijian and Indian student who selected the unsure option.

the entire range of fifty items, the scientific conception was more prevalent amongst Indian students in 45 instances, although in a number of cases e.g., items 23 and 36, this difference was minimal. Furthermore, Figure 6.2 reveals that for thirty three of the fifty items, Fijian students showed a stronger preference for the alternate conception.

The level of uncertainty in responding to the statements was also markedly higher amongst Fijian students, as in all but five items a greater percentage of Fijians than Indians chose the unsure option. However, these disparities may have resulted as much from differential schooling in science as any cultural factors. Certainly, fewer Fijian than Indian students who took part in the survey had pursued post-compulsory science at high school.

Overall the responses of the 143 student teachers who took part in this survey revealed some significant problems with their understanding of changes occurring in a number of common materials. In particular the SCS revealed that many students had a limited grasp of the relationship between energy and matter during these changes. These findings are elaborated in the following sections.

6.3.5 Detailed findings from the SCS

In this section the data from the SCS items have been classified according to the five conceptual subcategories within the CPIs, namely, change of state; conservation of matter; solubility; pressure; and heat. For each of these subcategories the data have been represented graphically, and certain individual items, for example those which indicate a very large disparity between the ethnic groups, run counter to the general trend, or are associated with qualitative responses of particular interest, have been highlighted in the discussion. In certain of these instances a two tailed test for significance of difference between two proportions (Bruning & Kintz, 1968) has been used to check for a statistically significant difference between the response frequencies of the two ethnic groups.

6.3.5.1 Change of state

Figure 6.4 shows the percentage scientific and alternative responses of both ethnic groups to the fourteen items from the SCS which fell into the category of change of state. Of these, seven items showed a degree of consistency in respect of response, insofar as there was no noteworthy difference between the prevalence of either the scientific or alternative conceptions between the two ethnic groups. Furthermore, the qualitative responses provided by each group on these items were very similar. For example, items 4 and 5 which dealt with the relationship between humidity and melting, and the concept of evaporation respectively, revealed almost identical response frequencies for the alternative conceptions held by the two groups with distinct similarities between their justifications. Both ethnic groups favoured the views that 'humidity provides the heat energy for melting to occur' and that 'the sun's heat absorbs water during the process of evaporation.'

However, the remaining seven items either displayed greater divergence between the groups, or the quality of the free responses made them worthy of particular mention. This approach of selecting certain items for specific attention has been applied to all of the categories discussed.

Thus in the category for change of state, items 2, 3, 6, 11, 13 and 37 revealed large discrepancies between the responses of the Fijian and Indian students. For example, although item 2 indicated that a very similar proportion of Indian and Fiji students held the scientific view that particles in ice constantly vibrate, significantly more Indian students (53.4% compared to 24.2%; $Z=3.569$; $p<.05$) selected the alternative view. The majority of both groups who made this selection justified it by stating that in solids the particles are held together tightly with no space to vibrate, a view which is clearly intuitive and strongly supported by the diagrammatic representation of solids in Fiji science course books e.g., Figure 5.2.

The analysis for item 3, showed that 63% of the Fijian students selected the scientific view, in contrast with 86% of Indians ($Z=3.731$; $p<.05$), while 33% and 11% respectively opted for an alternative view. The most common alternative conception, provided by the members of both ethnic groups in the free response section, was the belief that the condensation on the outside of the glass originated from the ice cubes or water within the glass. This was surprising as, in Fiji's hot and humid climate, condensation on cold objects is a very common phenomenon, and all of the students would have encountered the occurrence of condensation on sealed containers. This item also provided some evidence of the poor understanding of the relationship between energy and matter, with a number of students stating the heat energy became water vapour when it contacted a cold surface.

The view that light *and* heat were necessary for evaporation to take place (item 6) was quite prevalent amongst both groups (Fijians 64% and Indians 46% $Z=2.558$; $p<.05$). This perhaps derived from the strong association between light and heat in the tropics. Certainly the free responses indicated that this was the case with most students from both groups stating that where there is light there is heat, or that light changes into heat energy.

Items 11 and 13 dealt with condensation. Of interest was the fact that both items produced large disparities but this was reversed for the two groups between items. However, although the alternative conception presented in the former item was less popular amongst Fijians (49%) than Indians (62%) this was not statistically significant ($Z=1.850$; NS). The most widespread justification for this view was the anthropomorphic belief that 'vapour needs to change to water again.' Fijians also held a popular anthropomorphic view that 'steam will want to find a place to rest.' Equally common to both ethnic groups was the notion that 'hot and cold things attract each other.' There are other domains within science where the concept of 'opposites attracting' exists such as magnetism and electric charge. Some of the students may have transferred or 'chained' this conception to heat and cold in an effort to derive an explanation.

The alternative conception of glass sweating provided in item 13 proved extremely attractive to Fijian students, with 53% opting for this view compared with 11% of Indian students ($Z=6.367$; $p<.05$). This was most commonly justified by Fijian students in terms of the heat from the kettle being absorbed by the glass causing it to sweat, however, the majority of Indian students (78%) appeared to understand the distinction between condensation and sweating. From later discussion with students it transpired that 'sweating' was an analogy for condensation commonly used by teachers in Fiji. Not only was this analogy clearly misleading, but it seemed to be taken literally by many of the Fijian students, resulting in a teaching generated alternative conception.

Item 37 was intended to provide some insight into the mental models the students applied to a problem based on the different compressibility of liquids and gases. This item was the only negatively worded item in the survey, and although this may have caused some difficulty for the students, it was not apparent in the free responses. While only 47% of Fijian students believed correctly that the statement was false, this compared with 63% of Indians ($Z=2.274$; $p<.05$). Clearly in order to respond to this item it is important to have not only a particulate model of matter, but also one which can discriminate between the spatial distribution of the particles in liquids and gases. The qualitative responses indicated that many students did not make this spatial distinction because the most common response from both groups was 'there is hardly any space for the particles to move.' Others appeared not to consider spatial distribution or perhaps even particles as they stated, again in almost equal proportions, 'because both syringes are sealed and nothing can escape.'

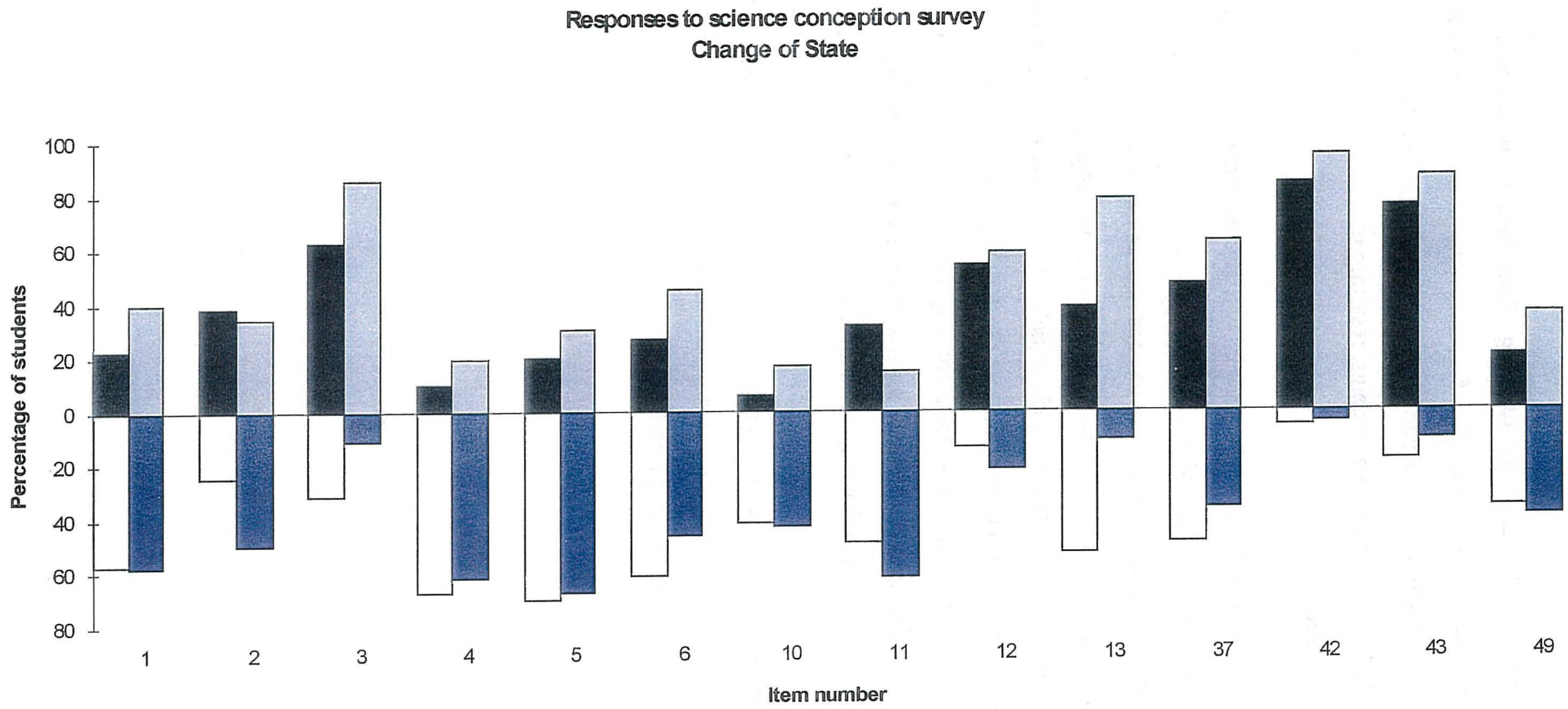


Figure 6.4. The correct and alternate response frequencies of Fijian and Indian to items relating to change of state. (Black = Fijian correct; White = Fijian alternate; Light blue = Indian correct; Blue = Indian alternate)

Finally, within this subcategory, item 49 proved to be of interest not because of the disparity between the groups which, for those who selected the alternative conception, was negligible (35.7% Fijian and 39.7% Indian Z=.584; NS), but because of the qualitative data it provided. This item stated that the particles which make up matter are living. In response to this the majority of students indicated that they held a variation on this alternative conception. This was the Aristotelian view that the particles can be living or non-living depending on the type of matter. Once again this tenet was common to both ethnic groups, and although more popular amongst the Indians, it did not appear to derive from any cultural root, but rather the intuitive belief that living tissue would be composed of living particles.

Overall, this section of the prevalence phase revealed certain similarities with the outcomes of the elicitation phase. It appeared to confirm the finding from the elicitation phase that Indian students were more likely to evoke a particle model of matter in dealing with states of matter. Certainly the response to item 37 lent support to this assertion. Furthermore, evidence of an anthropomorphic view of matter which emerged in the initial phase was shown to be quite widespread by the qualitative justifications provided for certain items in this phase. Finally, the notion that glass could 'sweat' which was presented by a single Fijian student during the elicitation phase, proved to be widely acceptable amongst this ethnic group, but not amongst the Indian students, none of whom had mentioned it during the initial interviews.

6.3.5.2 Conservation of matter and mass

Items pertaining to conservation of matter and mass revealed a considerable lack of understanding of this conceptual area amongst both ethnic groups. For instance, items 7 and 8 which referred to the composition of the bubbles in boiling water showed not only that a majority of both groups believed that these bubbles were composed of air (67% Fijians and 71% Indian Z=.612; NS), but also that a slightly larger proportion of the students held the view that water could be transformed into air at a certain temperature (84% Fijian and 71% Indian Z=2.201; $p<.05$). Both groups of students favoured the view that 'water has gaps filled up with air spaces which are released upon heating' to justify their response to item 7. This conception, although not scientifically correct, is consistent with the view that matter is conserved. However, many of these students clearly abandoned the notion of conservation when attempting item 8. Here the popular view was that when water evaporated it changed into air. It should be pointed out that it was never entirely clear whether 'air' was used by students in Fiji as a generic term for any substance in a gaseous state i.e., vapour. Nevertheless all of the students had been introduced to the composition of air during high school. However, in later discussions, all of the students were adamant that they had been taught that the bubbles in boiling water were composed of air.

Items 16 and 19 provided further evidence of poor understanding of the relationship between energy and matter amongst many of the students. For item 16, 41% of Fijian students believed that a burning candle produced only heat and light, while a further 24% indicated that they were unsure (Figures 6.5 & 6.3 respectively). The alternative conception was less prevalent amongst the Indian students with 23% selecting this option, the difference between Fijian and Indian groups being statistically significant ($Z=2.72$; $p<.05$). Once again the most prevalent justification for this selection was common to both groups, with Fijian and Indian students selecting the correct (i.e., 'false') response, but favouring the view that energy is also produced. The clear implication here was that these students were unaware that heat and light are forms of energy. Of those who gave an appropriate response, no one indicated that *both* carbon dioxide and water vapour were produced, although most cited one of these gases in their explanation.

Perhaps even more striking was the response to item 19 which indicated that 53% of Fijian students and 73% of Indians ($Z=2.929$; $p<.05$) believed that during a chemical change matter could be transformed into energy (43% and 22% respectively selected unsure). Most students justified this by stating simply that energy is released during the burning, with some Indian students mentioning particle breakdown. A number of Fijian students felt that all of the candle's matter would change into energy. Although the conversion of matter to energy during burning was clearly an intuitively appealing idea, it might have been expected that at least some of the students who had recently completed Year 13 chemistry and physics would have been more aware of the conservation of matter, as this topic along with the concept of activation energy, and energy release through the breaking and reforming of chemical bonds is covered at the Year 13 level. However, it is probable that they completed these aspects of science using different examples of chemical change and failed to transfer their knowledge to this novel context.

In approaching item 29, Fijian students displayed a lesser awareness of the conservation of mass, with 29% selecting the scientific view compared to 52% of Indians ($Z=3.313$; $p<.05$). As with item 37 mentioned previously, obtaining the correct response to this item appeared to depend largely on the ability to apply a particulate model of matter to the problem. Certainly students with the scientific view generally stated that the same number of particles would be present in the liquid and gaseous states given that the tube was sealed. Conversely, the majority of those who selected the alternative response appeared to have taken a macro view of the problem in which they had confused mass (weight) with density, as the most common alternative response across both groups was, 'the acetone in the liquid form is heavier than in the gas form.'

Finally, number 30 proved to be a poorly constructed item as the term 'combine', which had been intended to signify chemical combination, was interpreted as simply mixing by some of the students. Unfortunately this had not been identified during the pilot study and thus the value of this item was questionable.

This section of the prevalence phase appeared to confirm further the finding from the elicitation phase that Indian students were more cognisant of a particle view of matter than Fijian students. Certainly, this was strongly implied by the response data to item 29 which demanded the application of a molecular model. However, as in the elicitation phase, there was evidence to suggest that students were inconsistent in their application of this model. Hence, while a majority of Indian students seemed to apply this model appropriately to item 29, the same could not be said for items 7 and 8 pertaining to the bubbles in boiling water. Here, as in the interviews, both groups of students appeared to rely strongly on rote-learnt information from their school days. Finally, the lack of understanding of combustion, so apparent from the interviews, was also clear in this section of the prevalence phase,

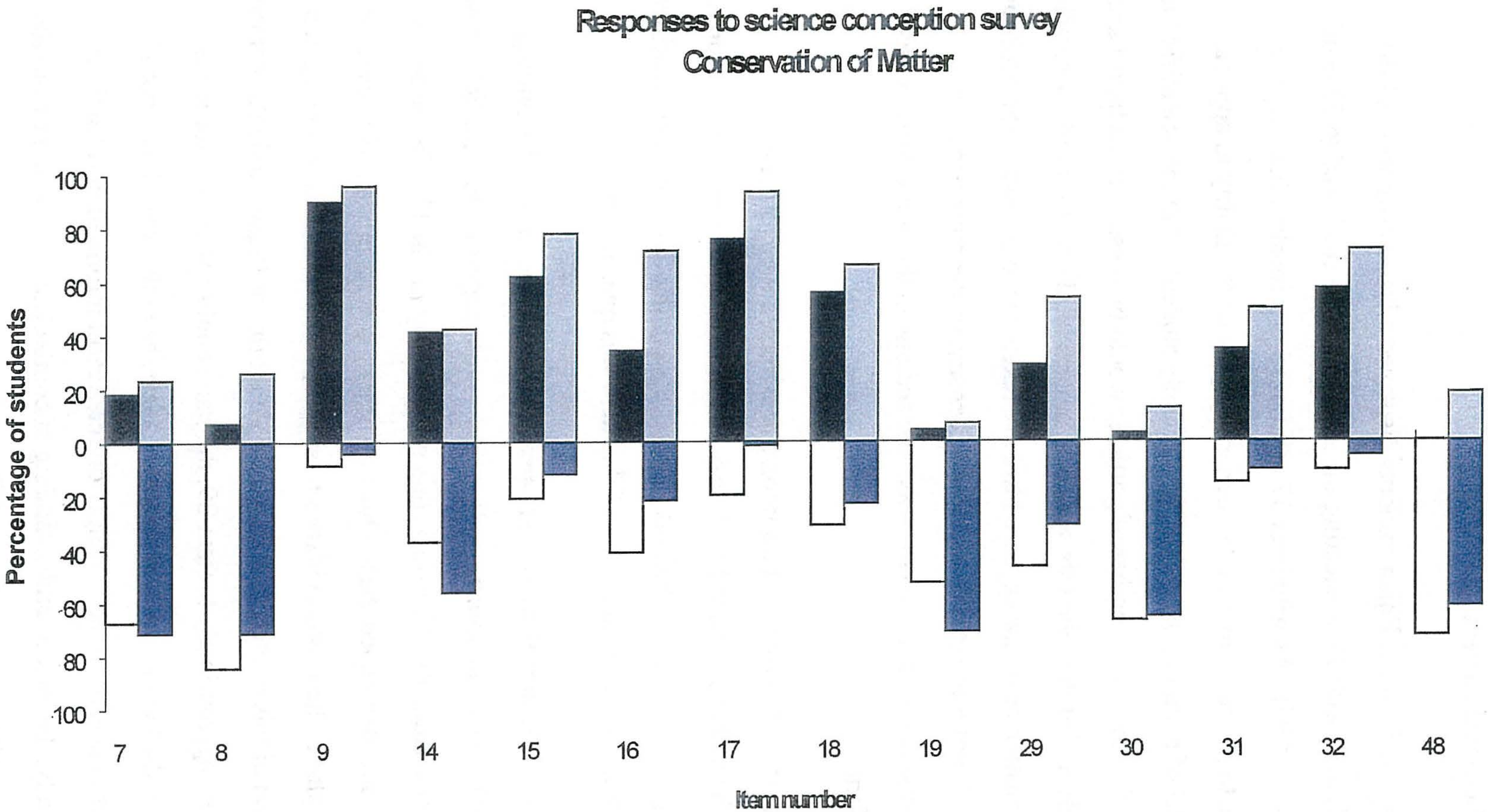


Figure 6.5. The correct and alternate response frequencies of Fijian and Indian to items relating to conservation of matter. (Black = Fijian correct; White = Fijian alternate; Light blue = Indian correct; Blue = Indian alternate)

which revealed that a large number of students were unaware of the chemical products of combustion or that matter was conserved during this process.

6.3.5.3 Solubility

With respect to the six items on solubility, four of these (21, 22, 24 and 25) showed a similar trend with a larger proportion of Indian students selecting the scientific response. Once again this seemed to indicate that, in general, the Indian students were more likely to apply a particle or molecular model to the statements than the Fijian students who seemed more likely to dwell on the surface structures. However, two items (20 and 23) produced data contrary to this trend and these, along with others that provided qualitative data of interest, are discussed.

A similar proportion of both ethnic groups (50% Fijian and 57.5% Indian $Z=1.064$; NS) believed that it was necessary for sugar crystals to melt in order for dissolution to take place (item 20). There was a marked difference between the groups in their view of item 21. This stated that sugar changed into water when it dissolved. Fijian students in general revealed less awareness of the conservation of matter during physical change, with 64.3% opting for this alternative view as compared to only 35.6% of Indians ($Z=4.059$; $p<.05$). This was also reflected by those selecting the scientific view, 21.4% and 53.4% respectively ($Z=4.676$; $p<.05$), with in most cases students stating that sugar could not change into water. However, in justifying their selection of the alternative view, students from both groups suggested that this was because sugar *must* change into water if it was to dissolve. Others had 'chained' the alternative conception presented in the previous item to this alternative view in order produce the explanation that 'sugar melts so it changes into water.' Both views were common to Indians and Fijians alike.

The Fijian students' apparently lesser awareness of the conservation of matter carried over to item 25, with only 52.9% cognisant that the dissolving of sugar was reversible, as compared to 83.6% of Indians ($Z=4.663$; $p<.05$). Again this was borne out by their qualitative justifications which suggested that the process was not reversible as the sugar had changed to water.

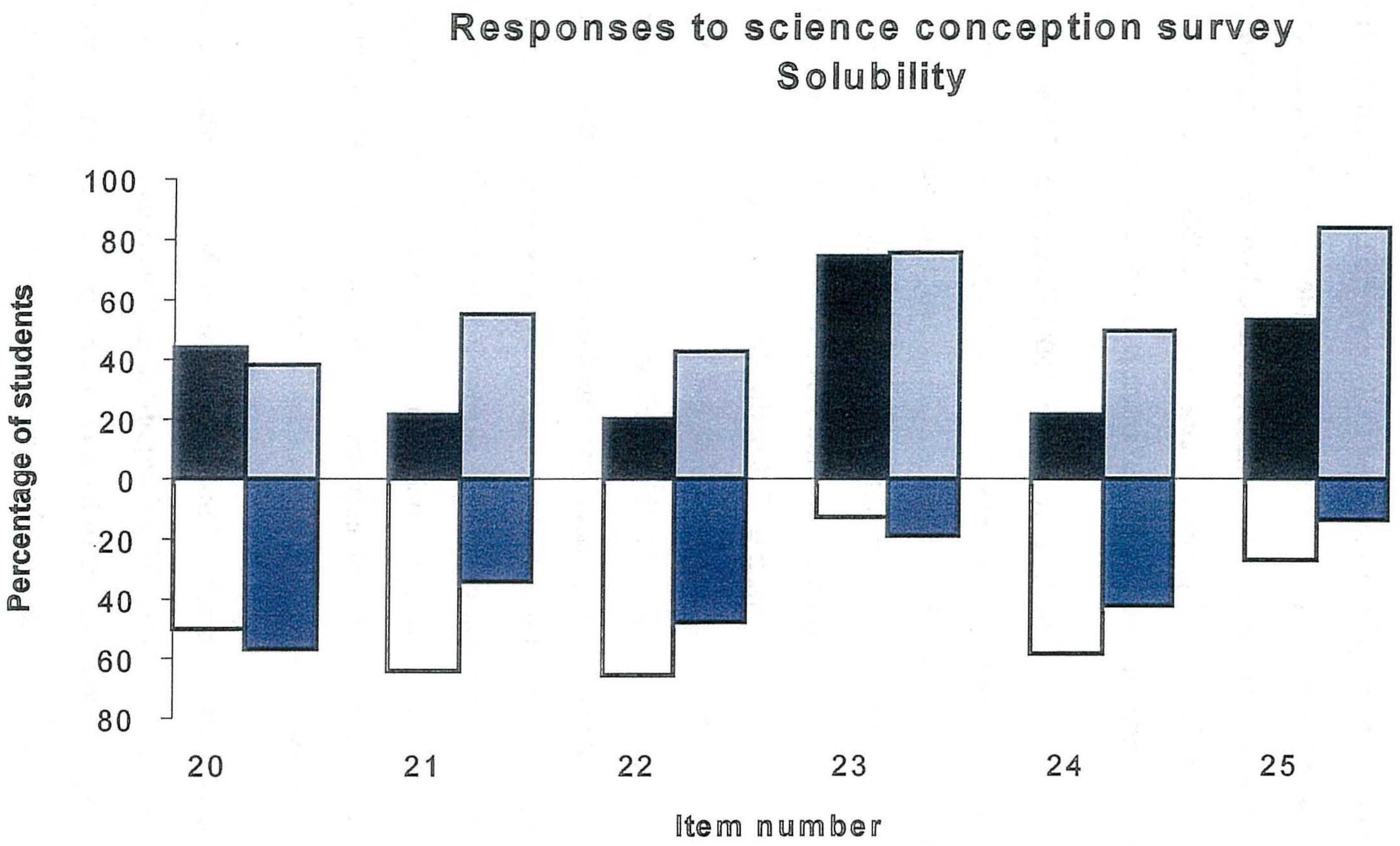


Figure 6.6. The correct and alternate response frequencies of Fijian and Indian to items relating to solubility. (Black = Fijian correct; White = Fijian alternate; Light blue = Indian correct; Blue = Indian alternate)

Although item 23 was answered well by both groups, with 74.3% of Fijians and 75.3% of Indians (Z=.163; NS) selecting the scientific view, this clearly contradicted the notion that sugar changed into water during the dissolving process. However, many students, in particular the Fijians, failed to recognise that their responses across the solubility items were contradictory.

Finally, the concept of saturation was not widely applied to item 24, even though all of the students had been exposed to it during their schooling. In total 64.3% of the students either opted for the alternative conception that the sugar crystals were too hard to dissolve or were unsure. Of the Indian students who selected the alternative conception (42.5%), most explained the presence of residual sugar in terms of strong bonding between the particles, while the most popular view amongst the Fijians (58.6%) (Z=2.277; p<.05) was that the residual crystals were insoluble.

The SCS responses to items relating to solubility were generally consistent with those from the interviews. Again they highlighted the disparity between the two groups in their ability or willingness to apply particle theory to scientific problems. During the elicitation phase eight Indian students made reference to particles when explaining various aspects of solubility compared to only two of the Fijian students. Conceivably, this might account for the disparity between the two groups on the majority of these items.

6.3.5.4 Pressure

Of those items on pressure which related to the balloon and bottle (26, 27, and 28), item 27 was poorly constructed as many of the students responded to the item in terms of the volumes of the balloon and bottle which they perceived as unequal. Conversely, item 28 proved to be very simple and as such was rather uninformative. However, item 26, although rather poorly worded, as it contained more than one premise, did provide some data of interest. While only 5.7% of Fijian students rejected the alternative conception presented, 24.7% of Indians did likewise (Z=3.742; p<.05). Amongst these students the most common explanation for their choice was that 'heat makes the particles move apart *not* become lighter.' A number of the Indian students incorporated the concept of particles gaining energy into their answers. Nevertheless, most students (82.2% of Fijians and 72.6% of Indians $Z=1.623$; NS) agreed with the statement that heat makes the air particles become lighter and move up into the balloon. The data obtained from the elicitation phase indicated that the students often made no connection between particle behaviour and increased energy. Given this scenario it might be logical for students to believe that the air particles had moved out of the bottle because they had become lighter or less dense. However, the most common justification of the alternative view was rather ambiguous as a majority of both groups stated that 'air expands when heated.' It was unclear if this meant that each individual particle expanded and became less dense or not.

A number of responses, mainly from Indian students, revealed further the poor understanding of the relationship between energy and matter. These students contended either that 'when particles gain energy they become lighter' or that 'heat makes things lighter.'

Of the remaining eight items which related to pressure (33, 34, 35, 36, 38, 45, 46, and 47) only item 34 which stated that gravity was involved in moving air into the balloon, revealed a large disparity. The remaining items showing a degree of consistency in terms of both response frequency and justification between the two ethnic groups.

Item 33 has also been highlighted due to the extremely poor response frequency to the scientific view which this statement exposed. The alternative conception that air can be sucked into a container proved extremely popular amongst the students with a total of 71.3% selecting this option. This also proved to be more popular amongst Indian students (82.2%) than Fijians (60%) ($Z=3.463$; $p<.05$). In the main, both groups justified this view by stating that 'space is created in the bottle therefore air is sucked in.' Only seven students in total rejected this view (3 Indian and 4 Fijian), and of these just two, both Indian, stated that the air was pushed in by the atmosphere.

The high prevalence of this alternative conception is not surprising given that, as in Western society, the notion of 'sucking' is in common usage in everyday discourse in Fiji. When asked to justify this view the students apparently generated the intuitive view that the 'empty' space created could exert a sucking force on the outside air.

For the following item (34) which stated that gravity was involved in moving the air into the balloon, 31.5% of Indian students claimed this was false and stated that the movement was due to air pressure. This response implied that, when considering this item, these students were thinking in terms of air being 'pushed', rather than 'sucked.' If this was the case, clearly some of these Indian students had employed different mental models when thinking about consecutive items.

The idea of gravity being involved in air movement was more popular amongst Fijians (48.6%) than Indians (31.5%) ($Z=2.468$; $p<.05$). While most students justified this by simply restating the item, a number of Fijian students stated that 'gravity is creating pressure which causes the air to move.' Again this appeared to be an example of 'conceptual chaining' in an attempt to derive an explanation for what was observed. This alternative conception was entirely absent from the Indian responses.

The data from the elicitation phase had indicated that the concept of pressure and pressure change was not well understood by most of the students interviewed, even those who had specialised in science at school. One of the reasons for this was an apparent lack of understanding of the relationship between pressure and volume in a fixed mass of gas. This was confirmed as widespread by the prevalence phase, where almost 60% the students failed to select the scientific response to item 35 which related volume to pressure. Furthermore, the key conception that colliding gas particles produce pressure, which was absent from the interview responses was also deficient in the SCS responses. Here only about 50% of students indicated an understanding of this concept (item 46) despite the 'cue' provided in the statement.

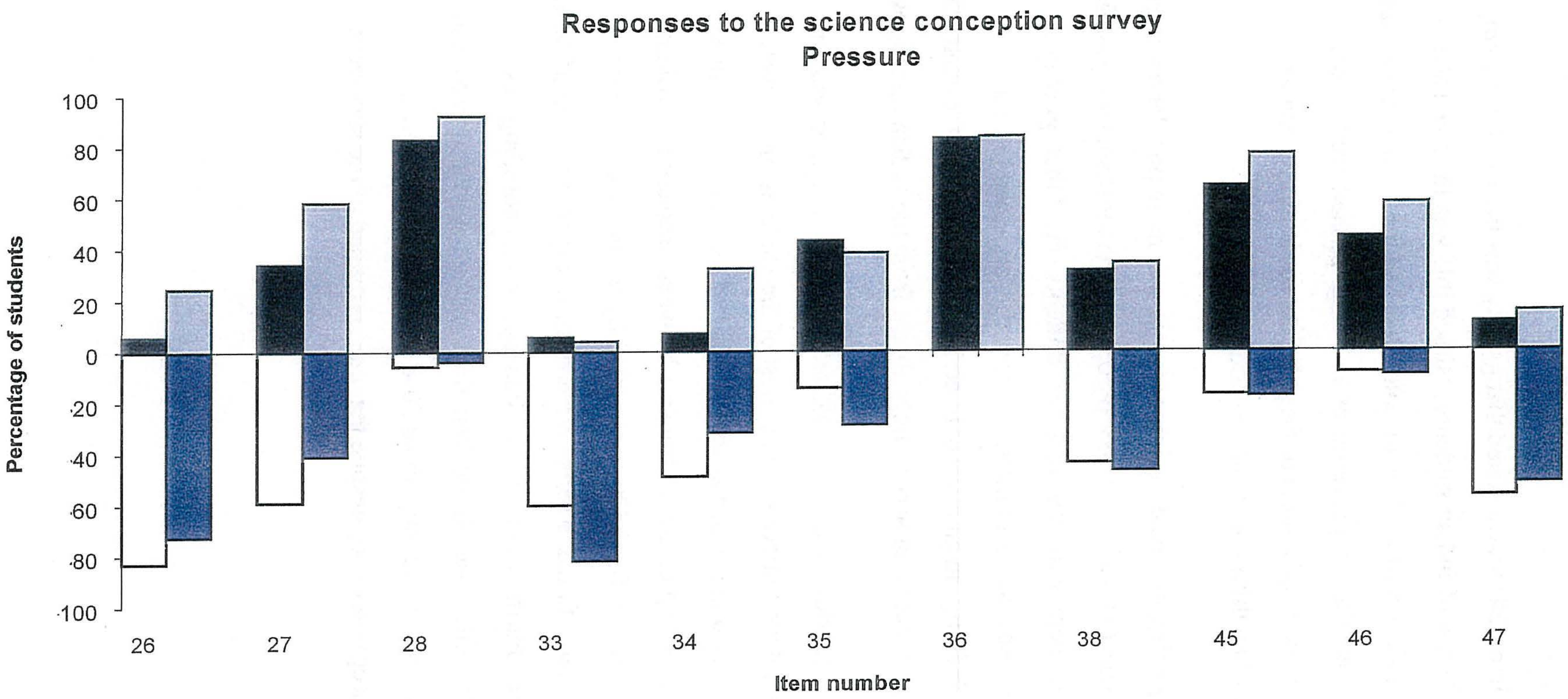


Figure 6.7. The correct and alternate response frequencies of Fijian and Indian to items relating to pressure. (Black = Fijian correct; White = Fijian alternate; Light blue = Indian correct; Blue = Indian alternate)

6.3.5.5 Heat

Once again there was a degree of consistency in the response pattern presented by both groups to the five items in this section. Thus, for example, similar proportions of Indians and Fijians believed that particles become bigger (item 39) or burst (item 40), if heated sufficiently, with both groups supplying markedly similar justifications e.g., 'When the particles cannot hold any more energy they will burst.' As a result two items are highlighted for reasons other than differential response frequencies.

The notion that air exists between the particles of a solid was used to construct item 44, on the basis that one Fijian interviewee had offered this as an explanation for metallic expansion during the elicitation phase. This alternative conception was selected by approximately equal proportions of Fijian and Indian students (28.6% and 27.4% respectively Z=.189; NS). However, although the expansion justification was common to both ethnic groups, the most popular explanation provided was one that stated 'air is present everywhere.' It appeared that this statement derived from the rote learning of a Basic Science course lesson undertaken in Year 7 and entitled 'Air Everywhere', aimed at introducing students to the notion that air was present in both soil and water. This lesson title had clearly been remembered from primary school by many students, when it had been interpreted literally and was now being applied incorrectly in a new context. It may seem surprising that students should have remembered this detail from as far back as Year 7 of their schooling, but in Fiji it is common practice for classes to chant key facts repeatedly in order to prepare them for examinations. This alternative concept may have been 'drilled' into many of the students in this way.

Finally, item 50 appeared to confirm the view of Bar and Travis (1991) that survey items can generate alternative conceptions. This item linked heating to the charging of particles as an explanation for expansion. Although this view was advocated by only one interviewee, it was selected by 40% of Fijian students and 28% of Indian students (Z=1.791; NS) during the survey. It seemed that this statement

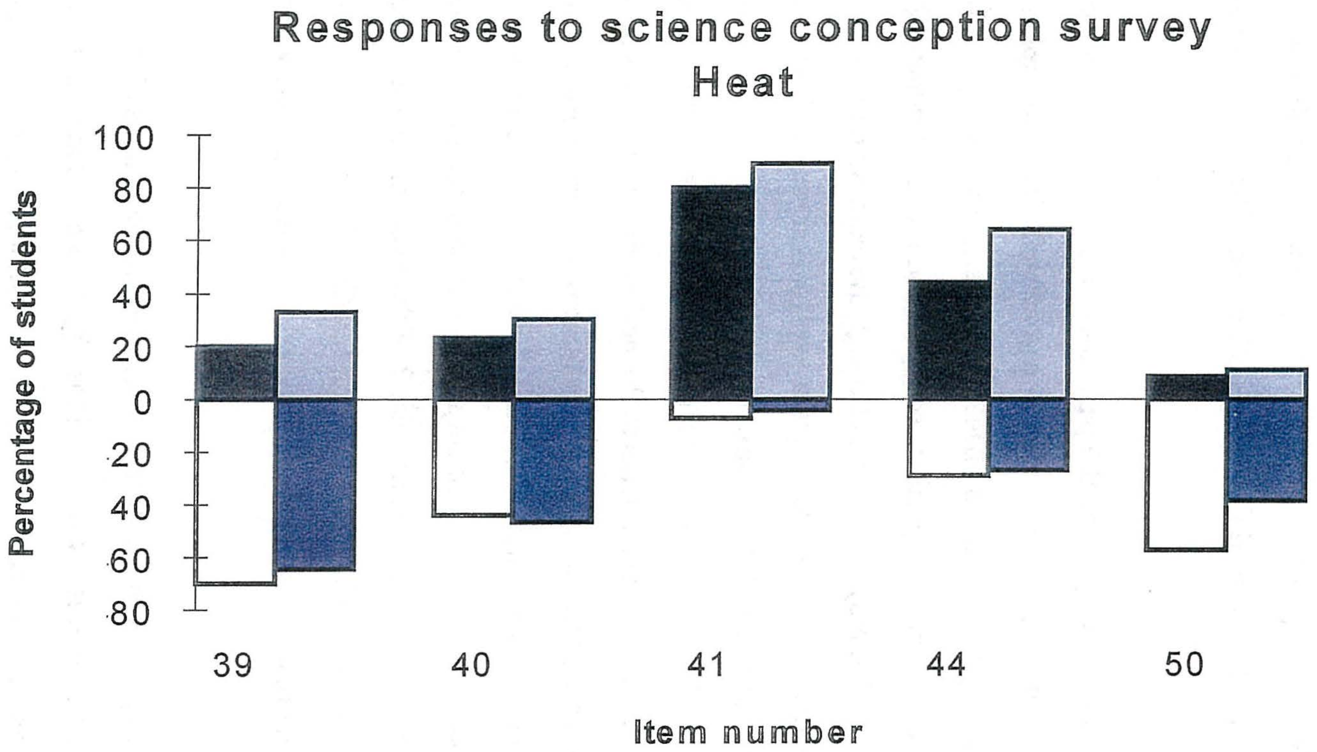


Figure 6.8. The correct and alternate response frequencies of Fijian and Indian to items relating to heat. (Black = Fijian correct; White = Fijian alternate; Light blue = Indian correct; Blue = Indian alternate)

appeared to be 'scientific' and thus appealed to a considerable number of students, in particular Fijians whose knowledge in this area was generally more tentative than that of the Indians. In addition, there was a 42.6% 'unsure' response to this item perhaps confirming a limited understanding of the energy/matter relationship at a molecular level.

Once again there was a strong degree of correspondence between the data obtained from the interviews and that from the prevalence phase. The 'expanding particle' conception expressed by seven of the interview subjects was also common amongst the wider student population (67%). Furthermore, it was clear from the interviews that most students had an understanding of the spatial changes between particles which result from heating and cooling solids. This was confirmed by the SCS with 85% of subjects selecting the scientific view that particles move closer together as a solid cools (item 41).

6.3.6 Summary

The most significant outcome from this phase of the research was that although there appeared to be a marked quantitative difference in terms of the scientific and alternative conceptions held by Indians and Fijians, there seemed to be very little qualitative difference in the alternative conceptions held. Certainly the data provided by the students in their free responses suggested that the alternative conceptions were qualitatively very similar. Once again this implied that there was very little evidence that the nature of alternative conceptions in this domain of science had any cultural origins.

Furthermore, the problems some students encountered in relating energy to matter, which came to light in the elicitation phase, were clearly shown to be very prevalent amongst a larger sample of the college. As mentioned previously this relationship is crucial for understanding many aspects of science and thus would need to be carefully addressed during the experimental phase of the research.

Finally, another conspicuous problem was the inconsistent use of scientific knowledge demonstrated by many of the students. There was evidence that students would employ a scientific view in the context of one particular item, only to abandon it when the context changed. Apparently these students were unaware of this inconsistency.

This chapter has achieved the first two objectives of the study, namely:

1. To identify and compare alternative conceptions held by individuals in the two ethnic groups.

2. To determine the prevalence of these alternative conceptions in the wider population of pre-service teachers.

As mentioned in each of the preceding sections, data obtained from the elicitation phase were largely supported by that from the prevalence phase, despite the different methods employed in each case. This lent support to the validity of the SCS as a data-collecting instrument and in fact the overall internal validity of the mixed methods study. Furthermore, these first two phases were successful in identifying the nature and extent of alternative conceptions about matter and how matter changes amongst the student population as a whole and also the two major ethnic groups within this population. Thus important baseline data were obtained about major areas of weakness in this domain such as the relationship between energy and matter and the conservation of mass and matter. This information was used to design a teaching program intended to provide the students with a better conceptual understanding of matter. The design and implementation of this program within an overall teaching experiment have already been described in chapter 5. In chapter 7, the quantitative outcomes of this teaching experiment are reported along with qualitative data collected both during and after the experiment. These qualitative data provide the basis for the final evaluation phase of the study.

Chapter 7

Results and Data Analysis of the Experimental and Evaluation Phases

7.1 Introduction

The previous chapter provided data on the nature and prevalence of alternative conceptions held by a sample of Fijian and Indian students from within the total college population. Thus it addressed the first two objectives of the study. The third objective, namely the design and implementation of the teaching intervention, has already been addressed in chapter 5. This chapter deals with the final objective of the research, namely:

4. To evaluate the impact of the intervention and in particular its comparative effectiveness with the two major ethnic groups within the student population of the college, namely the ethnic Indians and the indigenous Fijians.

Consequently, the data presented in this section will comprise quantitative outcomes for the experimental phase (Phase 3) of the study, along with qualitative data from the evaluation phase (Phase 4). The evaluation phase yielded qualitative data largely derived from group discourse obtained during the teaching experiment, and the views the pre-service teachers expressed on the various teaching strategies to which they were exposed. In addition to this, a final qualitative check of the students' conceptual understanding was undertaken by revisiting a number of the IAI cards and POE activities. This made it possible to compare qualitative concept profiles for individual students pre- and post-instruction. Finally, the results of an eleven item delayed post-test administered ten weeks after the post-test are discussed.

7.2 Analysis and results of the experimental phase

The effectiveness of the experimental and control treatments was assessed by comparison of the student teachers' scores on the pre- and post-tests, and later on the delayed post-test designed to assess conceptual understanding on the topic of *Matter and how it changes*. The analysis of the pre- and post-test data was carried out using a two-way analysis of variance (ANOVA) (*SPSS, 1993*) with the pre-test as the co-variate. The ANOVA compared not only the performance of the experimental and control groups, but also the respective performances of the two ethnic groups involved in the study. The results and analysis of the pre- and post-test data are presented in Tables 7.1 and 7.2.

Table 7.1

Comparison of Control and Experimental Group Performance on Post-Test, with Pre-Test as Covariate

Source of Variation	Sum of Squares	df	Mean Square	F
Covariates Pre-test	424.50	1	424.50	14.818***
Main Effects	939.30	2	469.70	16.395***
Group	878.40	1	878.40	30.663***
Race	3.65	1	3.65	.128
Group Race	20.70	1	20.60	.721
Explained	1623.50	4	405.90	14.169***
Residual	1260.50	44	28.60	

*Note: *** indicates significance at p<.001*

Table 7.2.

The Mean Scores and Standard Deviations of the Control and Experimental Groups on the Pre- and Post-Tests of Conceptual Understanding of Science.

Group	n	Pre-test mean	Pre-test SD	Post-test mean	Post-test SD
Control	23	21.43	6.82	22.52	5.95
Experimental	26	22.38	5.82	31.76	6.59

The analysis revealed that, after treatment, there was a statistically significant difference (p<.001) in the performance of the experimental and control groups on the post-test, with the experimental performing better. There was no statistically significant difference between the performance of the two ethnic groups, nor was the interaction between group and race statistically significant. Thus the experimental treatment did not favour either ethnic group.

While the post-test results obtained for the experimental group revealed that almost all the individuals improved on their pre-test performance, those for the control group indicated no statistically significant improvement on its overall pre-test performance ($t=1.48$; NS). This was a surprising outcome as the control group had covered ostensibly the same content. However, while the experimental group were exposed to teaching strategies derived from a constructivist view of learning, and designed to give students a better understanding of the underlying concepts about matter, the control treatment was heavily reliant on the Basic Science course books. Exposing the students to the practical activities in the book and following this up with a transmissive approach to the explanation of the underlying concepts appeared to have little impact on their overall understanding of the topic of matter. Consequently, it seemed to leave some of the students with only a superficial understanding of concepts they would have to teach in Classes 7 and 8. This was something which students who were interviewed later recognised.

There was also a further mitigating factor which may have accounted for some of the control group's performance on the post-test. Due to the nature of the timetable the experimental group completed the post-test during the first two classes of the week when they were 'fresh.' In contrast, the control group had to complete their post-test during the final two lessons of the week when they were obviously tired and keen to leave for the weekend. Unfortunately, this variable was entirely beyond the control of the researcher and had to be accepted as part of the normal variations within the college environment.

7.2.1 Summary

On the basis of the pre-test/post-test data, the experimental treatment appeared to enhance student performance in the domain of matter and how it changes. Overall the results and analysis of the quantitative data obtained from the teaching experiment established that:

1. The type of treatment made an impact, with the experimental group out-performing the control group

2. The experimental treatment did not differentiate between the racial groups

3. There was no group/race interaction on the post-test.

To enable a more detailed analysis of the results to be made, the data were subdivided into the five conceptual areas represented within the CPIs, namely: *Change of State; Conservation of Matter; Solubility; Heat; and Pressure.* Response frequencies for items categorised within each of these areas were calculated and analysed to provide mean gainscores for both groups and all individual students.

The following section of this chapter, the Evaluation Phase, draws on the large volume of qualitative data obtained from a number of sources while monitoring and evaluating the intervention to develop a comprehensive account of the teaching intervention.

7.3 The Evaluation Phase

The evaluation was conducted at two levels. Firstly, as the result of monitoring procedures employed during the teaching intervention, a considerable amount of qualitative data was obtained from the experimental phase of the research. This took the form of audiotaped discourse between the students during group work sessions, formal and informal discussions with the group's normal lecturer who audited the experimental sessions, and concept maps produced by the experimental group during the course of this treatment.

Furthermore, an interesting but difficult question was the extent to which the growth in the student teachers' understanding of specific concepts could be attributed to particular teaching strategies used during the experimental treatment. As Summers and Kruger (1994) point out, the only evidence available in connection with this question comes from the subjects' perceptions. These were elicited in a series of terminal interviews conducted after the intervention had been completed along with the students' views on how the experimental treatment compared with their previous experience of science instruction. At this stage it should be pointed out that, because there is a very strong tendency amongst many South Pacific cultures to tell interviewers 'what they want to hear', the researcher stressed at the onset of each interview that he wanted the subject's honest views. Further probing to elicit a clear justification for each subject's views on particular strategies tended to overcome this problem.

7.3.1 Analysis of the data obtained during the Evaluation Phase

7.3.1.1 Student discourse

The audiotaping of groups undertaking the control and experimental treatments provided a large amount of data. These were transcribed and carefully examined for evidence of concept development and higher level thinking. Of particular interest to the researcher was any indication of a qualitative difference in the discourse amongst the control and experimental students. Such data would confirm that there was a difference in the treatments and also provide indicators as to how students were constructing meaning from the various lessons. Thus some of the data which follow are examples of episodes of dialogue derived from both treatment groups which exemplify how these students approached the various group activities presented and, in particular, how they dealt with problems which required the discussion of specific concepts relating to matter. To this end each utterance (discrete segment of discourse attributable to an individual) within a given episode of discourse has been numbered. This allows easy reference to specific segments of dialogue mentioned in the discussion which follows each episode.

7.3.1.2 Terminal interviews

After transcription of the terminal interviews, the transcripts were coded according to the strategies or other issues being discussed by a given subject at any particular time. A total of six categories were then developed from this coding system. These included: *Comparisons with previous science instruction; An introduction to constructivism; Elicitation of alternative conceptions; Analogies and models; Collaborative learning;* and *Concept mapping.* The segments of each interview pertaining to a particular category were then cut and pasted into the appropriate files. Thus for example, all of the utterances made by subjects about analogies appeared together in a single file.

Data from all of the above sources have been integrated to provide evidence which might explain the difference in performance between the control and experimental groups on the post-test. The data obtained from members of the control group are presented first. Where student discourse is reported, double quotation marks indicate where students are reading aloud from the textbook or worksheet, or where they are verbally expressing what they are recording.

7.4 Control Group

As mentioned in chapter 5, the first control group practical lesson involved team teaching on the part of the researcher and the group's normal science education lecturer. On this occasion the lesson was introduced by the college lecturer.

> Lecturer: OK today you'll start off with Activity 11 and Activity 12 on States of Matter. So you will get this book (Basic Science Pupil Book)...not enough for all, so maybe you'll be sharing. Read the instructions that are given there. Please note it's very important that you note how the diagrams are drawn, cause when it comes to drawing diagrams we expect you to draw diagrams that are accurately drawn and fully labelled. In the first activity, lesson 11, what you do you discuss in groups but you write out your own lab work results, discuss in groups any work that you are doing but you write down your own method, you can use the formal eh method that we use in secondary schools, or you can just write down your results using the format set out in the book. Remember you have two sets of activities to do within these running periods, so it's best that you do the experiments and then you do your write up later on. You have enough apparatus and chemicals to work in groups. Have you decided which group you belong to?
> Students: Yes.
> Lecturer: So you read and when you're ready you can start with your activities.

This set the social context for the lesson, with the students working in groups and being encouraged to discuss the activities. However, although discussion was encouraged, the highly structured lesson plans presented in the Pupil Book appeared to inhibit the potential for high levels of reasoning to occur. Thus little conceptual knowledge was shared or reflected upon. The following episode of dialogue illustrates this characteristic of the control lessons. The students have been given pseudonyms. (Figure 5.2 in section 5.2.1 shows the particular lesson plan being discussed by the students).

7.4.1 Lesson 1 - Activity 11 - Change of State

(Nahida & Asha are Indian females; Amar is an Indian male)

1. Amar: (Reading) 'A pencil is a...Nahida write it...is a solid.'
2. Nahida: (Reading) 'Is a solid...its particles not able to...' (interruption by announcement from lecturer).
3. Nahida: (Reading) 'A pencil it does not change its shape...a pencil is a solid (laughs)...is a solid and its particles are not able to move around.'
4. Amar: (Writing) 'Particles not able to move around.'
5. Amar: (Reading) 'When put in a different container water...'
6. Nahida: Changes.
7. Amar: Changes?
8. Nahida: Yes it takes the shape of the container.
9. Amar : (Writing) 'Changes its shape.'
10. Nahida: (Reading) 'Water is a liquid and its particles are...free.'
11. Amar: Free to move around eh?
12. Nahida: Yes...(Reading) 'Use some of the words in the story of the pencil to help you fill in these spaces in the story of water.'
13. Amar: What about the flask?
14. Nahida: The water takes the shape of the container so water changes shape.
15. Asha: So it changes its shape?
16. Nahida: Yes it takes the shape of the container.
17. Amar: (Reading) 'Water is a...'
18. Nahida & Asha: Liquid.
19. Amar: (Reading) 'Name the three states and give three examples in each group.'
20. Nahida: Solid, liquid...
21. Amar: And gas.
22. Asha: Examples?
23. Amar: Pencil.
24. Asha: Tripod stand.
25. Amar: Not tripod stand...it's a test tube holder.
26. Asha: And glass block.
27. Asha: Liquid...
28. Amar: Water.
29. Asha: Spirit.
30. Nahida (Writing) 'Spirit.'
31. Asha: And oil.
32. Nahida: (Writing) 'Oil.'
33. Asha: What about gas?
34. Nahida: Eh oxygen...eh no...
35. Asha: Yes oxygen is a gas.
36. Amar: Carbon dioxide and nitrogen.
37. Nahida: What about methane?
38. Asha: (Reading) 'This jar contains a brown gas.'
39. Nahida: (Reading) 'Another jar is put on top. Shade the second jar to show where the gas will go.'

40. Amar: I guess it will go up there.
41. Nahida: Yes to fill up those spaces.
42. Asha: Yes.
43. Nahida: (Writing) 'The gas will go and fill up the spaces.' That's all.
44. Nahida: (Reading) 'Some sentences are written below. Copy out those that apply to solids under the heading solid, those that apply to liquids under the heading liquids and those that apply to gases under the heading gases.'
45. Asha: Why don't you number the sentences?
46. Nahida: (Reading) 'They may be hard.'
47. Asha: Solids.
48. Nahida: Solids.
49. Amar: Number the sentences first.
50. Nahida: Right number 1.
51. Amar: 1, 2, 3, 4, 5, 6, 7.
52. Asha: Number 1 is solids.
53. Asha: Number 2 is 'They are usually wet.'
54. Amar & Nahida: Liquid.
55. Asha: 'They keep the same shape'...solid.
56. Amar: Solid.
57. Asha: They can easily change their shape.
58. Nahida: Liquid and gas both.
59. Asha: Yes both.
60. Amar: Liquid too eh.
61. Nahida: Yes. 'Only flow downwards', liquid.
62. Amar: Flow downwards.
63. Nahida: Yes.
64. Asha: 'They flow in all directions.'
65. Asha & Nahida: Gas
66. Amar: Gas has any shape?
67. Nahida: I don't think so that gas has any shape.
68. Amar: Rub it off.
69. Nahida: I don't think it's right.
70. Asha: We can ask.

Although there were a number of opportunities within this episode for argumentation and exchange of ideas e.g., (5-12; 13-16; 33-37; 49-51) these were never pursued or were treated superficially. At one point Amar seemed unsure about the concept of free movement of liquid within a container (5-12), an issue which arose again (13-16) when both Amar and Asha made statements implying that they did not fully understand this concept. However, Nahida made no attempt to explain this concept further. Instead she simply repeated the assertion that liquid takes the shape of the container in an effort to gain a consensus and proceed with the activity.

Later in the episode (33-37), some discussion about examples of gases is initiated, in which Nahida questions whether methane is a gas. However, once again in an apparent effort to get on with the activity, this question was ignored by the other members who proceeded to the next problem.

Finally, towards the end of the activity (64-70) the students were confronted with a problem relating to the physical characteristics of a gas. However, instead of entering into any dialogue about this concept, the overriding concern was once again to come up with the 'correct' answer even if this simply involved asking the lecturer.

This episode was indicative of the nature of discourse conducted between small groups of subjects in the control group regardless of ethnicity. In general, the students' overriding concerns were with reaching consensus on the answers demanded by the text, clarifying procedural problems and issues of presentation (49-51). In fact, the highly structured activities with which they were presented demanded little else and offered little scope for higher level thinking. Furthermore, this student response was understandable as not only were these students assessed on the basis of their answers, but previous educational experience in Fiji may well have convinced them of the value of the 'correct' response and good presentation even at the expense of understanding.

A number of subjects from the control group and from groups taught concurrently by the normal science lecturer were later interviewed about their experience of learning science using the Basic Science text book as a focus. These interviews tended to elicit a common response which recognised that the control treatment (the normal college practice) did not provide sufficient depth to improve their understanding significantly.

> Nahida: It (the control treatment) does prepare us to teach when we go into the classroom, but this was mostly based on the book, we just learnt whatever the book wanted us to know. We did not really go into depth...we just tried to do the experiments and answer the questions that was presented in the book (Indian female-control group).

> Prakash: Well science teaching here...we are just touching on the book part and really what I think should happen we should be given explanations...on these facts. We got some explanations from our Form 5, 6 and 7 science but maybe they are not valid here so what I think is we should get explanations more (Indian male-normal lecturer's group).

Salina: What we did was eh of Class 7 and Class 8 standard science and it was not that challenging...
Researcher: Em...do you think it's important to know more than what is in the book?
Salina: Yes.
Researcher: Why?
Salina: As a teacher we should know more than what we teach...we have seen cases while we were on our teaching practice when we took science lessons the children ask questions which are not in the book...fortunately I had done science to a high level in high school so I was able to answer...but some who had not done much science it was hard for them to answer...so we should know more than what is taught.
Researcher: I thought children here rarely asked questions.
Salina: No we were in a town school and the children there were very smart. As soon as I went there my associate teacher told me, you have to be very careful, these creatures are very inquisitive...so I was doing a thing on tides...no no...about waves and one of them asked me 'Why is that?'
Researcher: So they did ask for explanations?
Salina: Yes things in Fiji are changing (Indian female).

One Fijian student was particularly concerned about this issue of insufficient science content knowledge.

Salome: I think we should have more background in science.
Researcher: Why?
Salome: Because when we go out to the teaching field, you know most of the students are very challenging you know. They can answer back your question and they can ask you more...lots of questions. So we have to be prepared to answer them...we have to have a science background.
Researcher: Are you worried about teaching science?
Salome: Yes I'm very worried because I didn't take science after Form 4 (Fijian female).

There seemed to some consensus that the way in which science was normally presented at the college did not provide sufficient depth of knowledge to prepare the student teachers adequately to teach science at the Class 7 and 8 level. Subjects frequently mentioned that they needed to move beyond the book as the activities provided were also viewed as insufficiently challenging.

These students felt that it was important to have a better understanding of the concepts which underpinned the science they would have to teach if for no other reason than to help them deal with students' questions in the classroom. But there also seemed to be some desire for an understanding of why things happened in science, rather than simply what happened. As one girl from the experimental group put it:

> Preeti: We didn't use to go into depth about everything. We just learnt it briefly on how to do the experiments and things, we didn't learn actually how it happened, we learnt only that it is going to happen (Indian female).

However, one Fijian female interviewed expressed satisfaction with the existing approach as she felt that anything more demanding would probably be too difficult and she did not enjoy science anyway.

Overall, the control group students perceived that they were not significantly improving their understanding. The control treatment represented the norm for second year science teaching within the college, and included explanations of the activities and concepts during the single lecture session each week. The lack of sufficient challenge provided by the lessons and the social context of the learning environment, with its strong focus on the text and emphasis on 'correct' responses was clearly constraining. This environment, although it involved a group work format, did not appear to encourage the social construction of knowledge through argument and the justification of ideas. Rather it stimulated a quest for 'correct' response consensus which generally discouraged higher level thinking and engagement in constructive discussion. Thus the opportunity to build a better understanding of the domain of matter was lacking with this approach.

This may explain the poor overall performance of the control group on the post-test in which no statistically significant gain was achieved over the pre-test performance even after six weeks instruction. In fact, even when the test results were subdivided into the five main conceptual areas of: change of state; conservation of matter; solubility; pressure; and heat, and re-analysed, no significant improvement in any of these areas was apparent.

The test was designed to check for improved conceptual understanding, but the treatment offered few opportunities for the students to construct a better understanding. The comments above suggest that many of the students were aware of the shortcomings of a textbook based approach. However, it was unlikely that these students would raise this issue with the lecturers, because teachers are still accorded great deference in Fiji. It would be culturally unacceptable in both ethnic groups for students to challenge their lecturer's teaching style. Furthermore, the overriding concern for most students was to pass the course and gain certification as a primary level teacher. Calling for a more demanding science course would clearly make this a more difficult goal. One student also commented:

> Prakash: What we do here is the book work...I told you before. But I think nobody can blunder with that guide book (Teacher's guide), if someone reads that guide they will have no trouble taking the lesson (Indian male-normal lecturer's group).

Understandably, being able to refer to a science guide composed of highly structured lesson plans offered considerable reassurance to many of the students about to embark on their primary teaching careers. However, this in turn was inevitably going to perpetuate the bookish approach to the subject which is so pervasive in Fiji schools.

7.5 Experimental Group

In this section data from a number of the lessons and activities included in the experimental treatment provide evidence of the kinds of learning experiences to which the students were exposed. Their reactions to these learning experiences are also presented. The first lesson with the experimental group on phase change was intended to assist the students in understanding the relationship between energy and particles and the notion that matter is conserved during physical change. The elicitation and prevalence phases had revealed these concepts were poorly understood by many students. Prior to forming small groups, the whole class had been involved in a discussion of phase change. This had involved discussing the students' views on a number of scientific and alternative conceptions derived from the Australian pilot study, observation of the Kinetic Theory model and discussion of analogies. The intention was to provide sufficient background knowledge for application to the problems they would discuss in their collaborative groups.

7.5.1 Lesson 1 - Change of state

Initially, the students completed the following activity: Put a few drops of acetone on the back of your hand, what do you notice? Explain why this happens using a simple diagram and writing. Why can you smell the acetone from a distance?

(Mere, Salote and Litia are Fijian females)

1. Mere: (Reading) 'Put a few drops of acetone on the back of your hand.'
2. Salote: Get the acetone from him.
3. Mere: On the back of your hand.
4. Mere: I should write this.
5. Salote: I'm just making some notes...in case I forget and then I'll write it later.
6. Mere: Yes especially for me I might forget. What do you feel?
7. Salote: My what's it...my thumb is cool.
8. Litia: Did you use your thumb or the back of your hand?
9. Salote: The back of my hand...the back of my hand feels cool.
10. Mere: Why is it like that?
11. Litia: That was liquid...acetone was liquid.
12. Salote:: Yes.
13. Mere: And when you put it on top...on the back of your hand it vaporises.
14. Salote: Yes it evaporates.
15. Mere: So the cold feeling you feel on your hand is the gas?
16. Litia: What did you say?
17. Salote: The back of my hand felt cold...the acetone is gone...
18. Mere: OK, OK...your hand...so that means...it...
19. Litia: I think that's what they put on our hand before an injection to make it numb too.
20. Salote: Just for this one it feels cold.
21. Litia: And the thing vaporises.
22. Salote: Yes it says explain why this happens...the liquid evaporises.
23. Litia: Yes it goes into the air...it evaporises.
24. Mere: What does that mean?
25. Salote: It's gas.
26. Litia: It means the liquid...the acetone turns into gas...

This short activity did produce some discussion between the subjects, however, this failed to get beyond observational descriptions into the underlying explanations for those observations. The subjects correctly identified the two key elements in this activity, the cooling effect on the hand (7-9) and the evaporation of the acetone (13-14) but they failed to link these effectively to construct a plausible explanation even at a macro-level. They seemed satisfied that deriving the correct scientific terminology for the disappearance of acetone represented an explanation (22-26).

In this case the students failed to apply any of the information which had been drawn out of the initial class discussion. To some extent this may have been symptomatic of an information overload, as a large number of potentially new concepts were covered in the initial discussion, resulting in confusion for those students with a weak background in science. Having reflected upon this during transcription of the audiotapes, which occurred directly after the lesson, the researcher attempted to limit the amount of future new material presented to the students to what he perceived was a more manageable quantity.

Furthermore, these students also suffered from a lack of any scaffolding which might have assisted them to make the link between energy and evaporation. However, this was the first occasion on which this particular problem solving format had been employed and towards the end of this episode there was some sharing of ideas about evaporation (22-26) in what appeared to be an attempt to construct a better understanding. Even at this early stage there was a sharp contrast with the control treatment where opportunities for knowledge construction were missed due to the strong desire to obtain the answers required by the textbook.

During the same lesson the students completed the analogous activity described by Stavy (1991) and outlined in section 2.7.2. This was intended to develop an understanding of conservation of matter and mass during evaporation. The episode below involves the same three Fijian females discussing this activity. It should be noted that the students misread the instructions and consequently reversed the sequence of the activity by evaporating the acetone before the analogous iodine.

1. Mere: Just read what it says there?
2. Salote: What happens...it disappears?
3. Mere: There's no more acetone in the thing (boiling tube).
4. Researcher: Don't heat it too much...what happened to it?
5. Salote: It evaporated.
6. Litia: It evaporated.
7. Salote: No you don't have to put the cork out, don't put the cork out.
8. Mere: It evaporates...
9. Litia: Which means it changes into gas.
10. Mere: So heating had something to do with evaporation.
11. Salote: Just ask him why...
12. Researcher: Yes you can ask me...don't be frightened to ask questions.
13. Mere: That heating has something to do with the evaporation.
14. Litia: Whenever you apply heating the liquid will evaporate...turn into gas.
15. Mere: Which means what?
16. Salote: What happens when you cool the tube?
17. Litia: It changes back to liquid. We got the acetone back.
18. Mere: What what...what happened?
19. Salote: What happens when you let the tube cool.
20. Litia: OK we get the acetone back.
21. Mere: So it evaporates and once the test tube cools down acetone gets back.

22. Salote: Now using a clean test tube put in a crystal of iodine.
23. Mere: Let me see this.
24. Salote: Heat over the flame.
25. Litia: You see iodine is inside.
26. Mere: But how can we get the acetone back if it evaporated?
27. Litia: Because once it was cool enough it changed to liquid again.

Having completed the previous activity in which the group had mentioned the concept of evaporation, they were quick to recognise that the 'disappearance' of the acetone in a sealed tube was also due to evaporation (1-8). Later, Mere presented evidence of development in her conceptual understanding of this process. During the previous episode, when the students applied liquid acetone to their hands, Mere seemed to be making a tentative connection between energy and evaporation (p. 269; lines 13-18). In this subsequent episode the connection emerged in a more coherent form (10-14) when she stated that heating had something to do with evaporation. It seemed that this concept was gradually being constructed during the course of the various activities and group discussion.

At this point the discussion was extended by Salote who wanted to know what would happen if the tube was now cooled. Litia was able to share her knowledge of condensation with the rest of the group (16-21). Mere still found the concept of condensation difficult to understand and asked for further clarification (26). However, the concept of condensation is impossible to explain without some reference to particle theory, and Salote was only able to restate her macro-explanation (27).

In this episode there was again considerable discussion between the subjects and as a result, Mere made the connection between evaporation and heating, and thus appeared to construct a better understanding. There seemed to be potential for the further construction of knowledge when the concept of condensation was introduced, as both Mere and Salote appeared to be unfamiliar with this process, or at least were unable to apply it in this context. However, any further construction was inhibited by the apparent deficiency of a particulate model of matter. This example illustrated the importance of individuals having sufficient knowledge to draw on if they are to take full advantage of the social context of collaborative learning. Even though this information had been provided through the initial class discussion it was apparent that these students did not apply it to the problems under investigation.

Later interviews with students revealed that the analogous iodine/acetone activity employed in this first lesson was not particularly successful. This activity was intended to convey the concept of the conservation of matter in the evaporation of acetone, as the preceding visually supported iodine task could be linked to the acetone case by the learners. However, it appeared that other stimuli such as the process of iodine sublimation, which itself was unfamiliar to many of the students, acted to distract them from the central concept of conservation. Furthermore, the iodine tended to resolidify rapidly after sublimation without its vapour filling the boiling tube in a convincing manner.

One particularly noteworthy aspect of this first lesson within the experimental treatment was some comments made by two Fijian females who had worked with a different group. These students were seeking some clarification on the energy/particle relationship after the lesson had ended.

1. Luisa: Sir like when particles gain energy...
2. Researcher: Yeah?
3. Luisa: Like they move faster?
4. Researcher: Yes.
5. Luisa: What if they lose energy?
6. Researcher: What do you think?
7. Luisa: That means they won't move at all or something?
8. Researcher: Well not that they won't move at all, but if they move faster when they gain energy...?
9. Luisa: That means they move slower when they lose energy.
10. Researcher: Exactly, that's why when you boil a kettle the water particles they start to move faster and then some of them get enough energy to take off and that's why you get...
11. Luisa: Steam
12. Researcher: That's right. We'll actually do a bit more on this on Friday...it was a bit rushed today and there were a lot of things to do but I hope it was OK.
13. Luisa: Yes it was interesting.
14. Mereani: Yes, because what we learned (at school) was that particles...the expansion and contraction of particles but not that particles gain energy or lose energy...like.
15. Researcher: Oh right so you didn't...
16. Mereani: So what we learnt today was something new.
17. Researcher: That's interesting...when you were in high school...what level did you do science to?
18. Mereani: Up to Form 4 (Year 10).

19.Researcher: But you didn't learn that they gained and lost energy?
20.Mereani: No it was just the expansion...
21.Researcher: That they move apart?
22.Mereani: Yes.
23.Researcher: Well they do, I mean that's right they do move apart but the reason they move apart is because they're moving faster or slower. As they move slower they come together and as they move faster they move apart.
24.Luisa: And it's the energy that makes them move fast?
25.Researcher: Yes...so it's the energy that makes them do that...it's usually heat energy.
26.Mereani: Which makes them move faster....
27.Researcher: Yes which makes them move faster and as a result they move further apart OK, and as they lose that energy they start to move slower so they come together again. Now if you have something like a metal and you heat it they start to move apart and the whole metal ball gets bigger...
28.Luisa: Yes.
29.Mereani: So sir what you're trying to say is that the particles in the metal ball don't expand...but because they gain energy...they move apart therefore that metal ball expands.
30.Researcher: That's right.
31.Mereani: It is the metal ball that expands not the particles.

These students indicated that during their respective school science careers they had learnt that the particles in matter could move apart as a result of heating (14-22). However, they had never associated this with the gaining of energy (19-20). One possible reason for this is that static two dimensional diagrams are often the first introduction to particle behaviour which students in Fiji receive. These show the particles of matter with different particulate spacing depending on the phase, but do not readily convey the concept of the energy interaction (see section 5.2.1; Figure 8). On a later occasion the same students were asked what, during their school days, they thought happened to the particles after they had moved apart and the heat source was removed. One stated that she thought they simply remained apart, while the other claimed she never fully understood what happened.

However, these students were now seeking to make connections with their previous knowledge in order to make sense of the new information and in so doing they appeared to have developed some conception of the energy matter relationship. Their questions helped to clarify this further. In fact Mereani was able to articulate and reiterate the researcher's explanation of expansion very effectively (27-33).

Students later contrasted their previous introduction to particle theory with that employed during the first lesson of the experimental treatment. Only one student had been exposed to anything other than a text book representation. This particular student had a clear recollection of an analogous representation provided by his teacher to convey the particulate nature of matter.

> Researcher: How were you introduced to the idea of particles?
> Vijay: Well I just remember one thing about when I was taught about particles. The teacher used to break up pieces of chalk to show us the powder and the big pieces and the small pieces (Indian male).

This apparently vivid memory even after six years may be indicative of the effectiveness of analogical reasoning in this context.

The other students interviewed maintained that they had never encountered a demonstration model or analogical representations of particle behaviour even though all had been introduced to the concept of the particulate nature of matter during high school. Instead the concept had been presented in the set school text as a series of diagrams which some students found difficult to understand.

> Salote: In high school they had particles in this shape...circles and we couldn't understand much and there was something written in the circles.
> Researcher: I see...you did this in Form 4?
> Salote: Yes.
> Researcher: And there was something written in the circles?
> Salote: Well...there were some black circles and some white circle (Fijian female).

> Mereani: When we looked at the pictures we could see that the particles moved apart when they were heated...we didn't know they gained and lost energy.
> Researcher: What did you think happened to the particles when the substance cooled.
> Mereani: I didn't know (Fijian female).

The students claimed that the strong visual representation provided by the Kinetic Theory model was helpful in improving their understanding of particle behaviour and in particular the relationship between particles and energy.

> Researcher: Why did you find the particle model particularly helpful?
> Salote: Because you can actually see the particles move...you can see how they lose energy (Fijian female).

> Mereani: Well for example like I could see...when we apply energy I can really know that the size of the particles and the number remains the same

even though energy was...there's loss of energy or there's gain of energy the particles remain the same (Fijian female).

Researcher: Before you came to my lessons were you aware of the fact that particles can gain and lose energy?
Tevita: No.
Researcher: Can you think of what helped you understand the concept better?
Tevita: I'd say the use of that model.
Researcher: What was it about the model which you found helpful?
Tevita: Because you can actually see how the particles move...you can see how they lose energy and gain energy (Fijian male).

Students claimed they also found the analogies particularly effective because they were able to link them to their everyday experiences, and a number of students recalled specific taught analogies when discussing this aspect of the instruction. One mentioned an analogy in which migration was linked to evaporation.

Preeti: There's lots of people and then they migrate eh from for example Fiji to America, then the other poor are left so they need more money...I mean if they work hard and get more money then some more migrate...and it's the same with the acetone...it needs more energy...some of them evaporates the others are left...they need more energy (Indian female).

Although not a perfect explanation, this Indian student had grasped the idea that energy is required for evaporation to take place. This was a particularly apt analogy for Fiji where the migration of wealthy and/or well educated Indians to Western countries is commonplace.

Another student recalled an analogy intended to help convey the idea of matter as particulate.

Researcher: Did you understand the analogies we used?
Vijay: Yes especially the one on the beach...looking from a distance at the sand.
Researcher: What was that trying to do?
Vijay: Looking at particles from a distance...sand from a distance is just solid, but when you look at sand pieces...particles from a few yards we can see the grains, but from a distance it will just look...we'll see it looking just white (Indian male).

A number of students remarked that they would try to employ analogies in their own teaching where possible.

7.5.2 Lesson 2 - Change of state (continued)

The second lesson continued the theme of phase change and once again was intended to encourage the students to construct explanations of various phenomena using the particle/energy relationship. The initial discussion again incorporated the Kinetic Theory model to help illustrate the interaction between particles and energy. This was a further attempt to provide information which the students could share and apply in the construction of their explanations to the activities on phase change.

On this occasion the students' own conceptions were elicited, rather than using examples from the Australian study. The students responded to questions quite readily and the ensuing discussion revealed that 'the water to air' alternative conception was highly popular. As this had been anticipated on the basis of the data from the first two phases, the second group activity had been devised to encourage the students to think more intently about this notion. In the first activity the students were asked to explain the presence of condensation on the outside of an ice-filled bottle, using particle theory.

7.5.2.1 Activity 1 - Condensation on ice filled bottles

(Sakiasi is a Fijian male; Mereani is a Fijian female and Sheetal is an Indian female)

1. Sakiasi: (Reading) 'What do you observe on the outside of the bottles of ice?'
2. Sheetal: That's condensation eh?
3. Sakiasi: Yeah condensation.
4. Mereani: Release of heat energy.
5. Sakiasi: These are water droplets eh.
6. Sheetal: Wipe it.
7. Mereani: (Reading) 'Explain what is happening in terms of particles and heat energy.'
8. Sakiasi: There is release of heat energy because...
9. Mereani: Was he comparing it to sweat...did he say the glass was sweating?
10. Sheetal: No here the water particles they get attached to the bottle they come from the air...the water particles in the air are attached now to the what...they get stuck to the cold surface.
11. Researcher: Are you familiar with this?
12. Mereani: Yeah.
13. Researcher: What do you call the process?
14. Sakiasi: Condensation...this is condensation...so what happens is that...what...
15. Mereani: The particles from...the water particles from air get stuck onto the cold surface.

16. Researcher: Yes there are always some water particles in the air...
17. Sheetal: Yes...when they hit the cold surface...they lose energy...
18. Mereani: Yes they lose energy.
19. Researcher: Exactly what happens then?
20. Sheetal & Mereani: The speed gets slower.
21. Sakiasi: So it's just the losing of energy eh...the losing of energy they move slower and that's why they...get stuck onto the bottle like there's a force between...
22. Mereani: Once they're closer to the thing they lose energy.
23. Sakiasi: When they get stuck on the thing they lose energy because of the coldness.
24. Sheetal: (Writing) 'The particles in the air loses energy...so they slow down...he was saying what...the force...there's a force there's a very little force between the bottle and the water particles that's why they form into water and eventually they will trickle down.'
25. Sakiasi: OK what's the next?
26. Mereani: So the process that's taking place there was condensation...water particles from the atmosphere...
27. Sheetal: The process taking place is condensation...he said when the particles are close to the cold surface there is a force between the particles...there is a weak force, is that what he said? When the particles gets closer.
28. Sakiasi: Yeah...no why does the water trickle down then...why does it just not stay there.
29. Mereani: He said because there is a weak force between the particles and the bottle...that's why water is forming...eventually it will trickle down because of the amount of water.
30. Sheetal: Yeah.
31. Mereani: Because there are millions of water particles...
32. Sakiasi: Oh right, right.
33. Mereani: So there is not enough space for them to stay on the bottle...they'll eventually trickle down.
34. Sakiasi: It gets heavy eh?
35. Mereani: Yeah
36. Mereani: (To a member of another group) You want the explanation for number one?
37. Student: Yes.
38. Mereani: In the atmosphere there are water particles...there are water particles in the atmosphere...when they hit a cold surface they lose energy, therefore they slow down.

The group featured above was of mixed ethnicity. This was less usual than the formation of mono-ethnic groups, but was by no means unique. These students correctly identified the phenomenon in this activity as condensation, and Meriani was quick to associate this process with energy loss (4). The discussion with the researcher at the end of the previous lesson (pp. 272-273) revealed that this student had embarked on the treatment with very little understanding of the role of energy in phase change. However, she was now clearly beginning to construct a notion, at the macro-level at least, which was in keeping with the view of science.

Nevertheless, a little later in the episode (9), this same student provided a good illustration of how readily instruction can generate alternative conceptions. In this case she had mis-heard or mis-interpreted a discussion about analogies in which the sweating analogy was held up as a bad example. However, this was ignored by the others and Sheetal then introduced three new concepts to the discussion, particles and the idea that these had come from the atmosphere, plus the concept of adhesion (10). This then initiated further discussion (10-24) in which all of the group members participated, and eventually constructed a scientifically coherent model of condensation (24). The concept of adhesion was then discussed further. Sakiasi raised the logical question of why water droplets would trickle down a surface if they were attracted to that surface (28), and the other group members were able to supply an explanation (29-35).

This episode showed students collaborating effectively to apply a particle model in their construction of an explanation for the process of condensation. The students were prepared to ask each other for clarification when necessary and there was no reluctance to share conceptual knowledge. Furthermore they appeared to be able to draw on concepts discussed at the start of this lesson and in the previous lesson and link these to the concept of condensation. However, in the context of the whole class, the concepts of adhesion and cohesion introduced at the start of the lesson did cause considerable confusion. It became clear later that the minute distances over which these forces act was apparently not understood by the students. This was reflected in the performance of post-test item 11, where preference for the alternative conception rose from 57.7% to 69% amongst the group. Hence this alternative conception had been reinforced by the instruction.

7.5.2.2 Activity 2 - Evaporation and condensation of water.

In this activity the students were required to boil a small amount of water in a test-tube and condense the resulting vapour on a mirror. They were supplied with a table showing the composition of air and asked two questions about water and air, which they were to discuss and resolve. *(a) What are the bubbles you see made of? (b) How were those bubbles formed?* The episode below involved the same group as previously.

1. Mereani: Keep boiling it.
2. Sakiasi: Nothing happens.
3. Mereani: Wait we just observe what's happening see...see when the steam hits the mirror...there you see that?
4. Sakiasi: Oh yeah.
5. Mereani: See the thing there?
6. Sheetal: Oh yeah.
7. Mereani: That's just the same thing.
8. Sheetal: See the water particles there get stuck on the...
9. Mereani: OK what happens...it's the same thing eh? Water vapour was coming out from the test tube eh and when it hit a cold surface...the mirror was the cold surface...and it condenses....so what's that...that's condensation too?
10. Sheetal: Yeah.
11. Mereani: Condensation...water vapour was coming up...
12. Sakiasi: Are you sure it is condensation?
13. Sheetal: Because the mirror is a much colder surface than that so when it touches that...
14. Mereani: It is condensation...come on!
15. Researcher: So what happens here?
16. Sakiasi: I think when you heat the test tube with water the vapour comes out and hits the...
17. Sheetal: This surface here...
18. Researcher: And what happens?
19. Sheetal: It forms back into water particles.
20. Mereani: Yes it's condensation...
21. Researcher: What about the two questions there? The composition of air just means what air is made up of.
22. Sakiasi: Vapour is gas phase eh?
23. Sheetal & Mereani: Yes.
24. Mereani: And the bubbles in the boiling water are made up of air?
25. Sakiasi: Yes, because water contains eh air particles so when we heat it...
26. Sheetal: They heat off.
27. Sakiasi: Form bubbles...like when we do the soil experiment with water...the soil is full of air so we get bubbles coming out...that's the same thing.
28. Mereani: The bubbles in the boiling water are made up of air?
29. Sakiasi: What else could the bubbles in the boiling water be made up of? (laughs)
30. Sheetal: Yeah it's air.
31. Sakiasi: So that's the answer to the first question?
32. Sheetal: Actually the bubbles is a space between the particles in the air...once they get heated up they expand.
33. Mereani: No there is no space...I mean there is space but there is nothing in the space see that...what are you trying to say...it is the space between the air particles? I don't know.

34. Sakiasi: The boiling water particles they are sliding past each other...if you heat them up you get air, so that's why when we boil the water that's the air particles...
35. Mereani: Wait just do it again.
36. Sheetal: No no no you see in the water there are air particles and water particles so what are the bubbles...
37. Sakiasi: When it was boiling...when it was boiling...what else do you think it could be?
38. Sheetal: It is the va...no...I thought it was a vacuum you know.
39. Sakiasi: It was a what?
40. Sheetal: Yeah just look at the bubbles.
41. Mereani: OK talk about particles and energy...particles and energy.
42. Sheetal: Yeah OK when you are heating water eh the particles in water they gain energy, therefore they move faster eh that's why they slide around more...when they move fast bubbles also appear so...we have to explain...
43. Sakiasi: What's those bubbles.
44. Mereani: Yeah whether those bubbles are made up of air or they are just spaces or something in the boiling water...that's one thing we have to find out.
45. Sheetal: The bubbles in the boiling water are made up of air...is it true or not?
46. Sakiasi: It's true...more vibration takes place.
47. Sheetal: Because the air particles...the energy...
48. Mereani: OK wait...see he told us to look at this...hey you two just listen...water is H_2O or HO_2?
49. Sheetal: H_2O.
50. Mereani: So O is oxygen eh?
51. Sakiasi: Yes
52. Mereani: And H hydrogen...so of course water contains air...see because composition of oxygen see that's 21%...there's 21% of oxygen in air...and water contains air therefore the bubbles in boiling water is air.
53. Sheetal: Of course.
54. Mereani: Is that the explanation.
55. Sakiasi: Sheetal is right.
56. Sheetal: No she was right but she could not find an explanation for her...
57. Sakiasi: But also...carbon dioxide.
58. Mereani: Water's made up of hydrogen and oxygen.
59. Sakiasi: So the bubbles in the boiling water are made up of air that's true.
60. Mereani: And what is the next one?
61. Sheetal: How were those bubbles formed?
62. Mereani: When water is heated it changes into air.
63. Sheetal: Yes because when water is heated it forms vapour...vapour is gas phase gas...in other words air...
64. Mereani: Wait don't talk in complicated things...you just talk using particles and energy.
65. Sheetal: OK water particles are heat...
66. Mereani: When water is heated?
67. Sheetal: Right when water is heated the particles in water they gain energy and they...and to move up...

Tape ran out

Despite the change of context Mereani and Sheetal where quick to make the connection between this activity and the previous one, insofar as they identified that both involved condensation (8-14). However, when it came to a discussion on the nature of the bubbles, all three students were initially satisfied with the alternative view that these were composed of air. In an attempt to justify this view, Sakiasi linked the concept back to a specific Basic Science lesson entitled 'Air is Everywhere' from his school experience, in which the presence of air was demonstrated in soil (27). At this point the focus changed to the spaces between the particles within the bubbles and the students embark on constructing the notion that the bubbles contain a vacuum (32-38).

Nevertheless, Mereani, appeared dissatisfied with this view and clearly wanted to apply her recently acquired construct of the energy/particle relationship to the problem. This approach prompted a much more precise articulation of the problem. (41-44). However, in attempting to incorporate the data on the composition of air into their discussion, the students began to construct a view of boiling which involved the dissociation of water. This view was very similar to that constructed by some Australian students in the pilot study These students had constructed a model of boiling based on what seemed to be their knowledge of the formula of water and partially remembered aspects of electrolysis in which the decomposition of water does take place.

In the final section of this episode, Mereani once again attempted to incorporate the particle/energy construct into the discussion (64). Although this student failed to develop a scientific view of boiling, she was developing her thinking in the correct direction, as she correctly believed that problems could be explained using particle theory. However, this activity illustrated that the provision of scaffolds (in this case data on the composition of air) without proper explanation could prove misleading.

Nevertheless, these activities generated plenty of discussion, and it was noteworthy that the students demonstrated considerable perseverance and co-operation in tackling the problems set. Moreover, they were not simply satisfied to settle for the first explanation constructed, but were willing to test each explanation against their existing knowledge. There appeared to be a genuine determination to develop a better understanding and consequently some of the notions generated were rejected and others developed. This determination was such that the group failed to consult the researcher during the episode. Clearly some scaffolding from this source may have helped the students develop the scientific view.

These lessons comprised the formal treatment of the topics of state change and conservation of matter. However, these topics were occasionally revisited during the remainder of the treatment. It was noteworthy that in the conceptual area of matter conservation the student mean gainscore for the experimental group on 14 items was 3.65. In other words, on average students in the experimental group improved their score by 3.65 marks or 7.3% on the post-test over the pre-test on these 14 items. In fact, all but one student from the experimental treatment showed improved performance in this topic. This outcome may have been due in part to the use of models and analogies to convey ideas of matter conservation. Certainly students claimed that these strong visual representations allowed them to appreciate that the number and size of particles remained constant during phase change. This contrasted with the control group who were not exposed to either the models or analogies and achieved a mean student gainscore of only 0.39 on the same 14 items.

The difference in the mean gainscores achieved on 14 items relating to change of state was less marked. These were 2.31 and 0.48 for the experimental and control groups respectively. Although this represents a smaller difference than that for the conservation items, it still suggests that the strategies employed with the experimental group were more effective than the book-centred control strategy.

From later interviews it transpired that the alternative conception about the bubbles in boiling water was held with great tenacity. All claimed the notion that the bubbles in boiling water contain air had been taught in school and that it was the accepted response in the national examinations. Some students had obviously reflected on this issue during the week which followed, and consequently in the next lesson one student asked about this dilemma.

Saleshni: When we are teaching in primary school are we going to teach them that it's water vapour and not air (in bubbles).
Researcher: Well if you teach them that it's air then that's not considered scientifically correct.
Saleshni: But that's what we learnt at primary school...and when they do external exams like Fiji Junior they expect air as the answer.
Researcher: The students have to write air?
Saleshni: Yes that's what we learnt that it's due to air, and that is what the examiners expect.
Researcher: That's not a problem I've come up against before...usually the exam requires the scientifically correct answer.
Saleshni: But air is the answer we have to write.
Researcher: So for the exam you have to write air?
Saleshni: Yes they mark it right.
Researcher: OK I'll try to check that out for you.

It turned out that there was no evidence for this assertion in the Basic Science texts and a member of the Education Ministry's examinations section also denied that this alternative conception was an accepted response in the national science examinations.

Even after considerable discussion, the use of the Kinetic Theory model and the introduction of various analogies several students were still very sceptical of anything other than the alternative view of the composition of the bubbles. This was apparent from later interviews.

Researcher: From the discussions we had and the activities we carried out, were you ever convinced that the bubbles in boiling water were water vapour?
Mohini: Not really...no.
Researcher: You are still inclined to think it might be air?
Mohini: Yes, because from the beginning we have been taught that it's air present not water vapour...and then you tell us it's water vapour and it's quite confusing (Indian female).

Although Mohini appeared to lack a sound understanding of this concept she was able to produce the correct response to the items relating to boiling water in the post-test. This suggested that she had rote learned the appropriate response. Thus despite the intention of providing improved conceptual understanding, some students within the experimental treatment were apparently still relying on learning by rote.

When students were asked to give their views on the process of eliciting preconceptions at the beginning of each lesson, most stated that they found it valuable to discuss these and were not uncomfortable when these proved to be different from the scientific view. A number tended to blame their alternative conceptions on the poor teaching they had received at school.

> Researcher: How did you feel when we discussed people's ideas in class and you discovered that your ideas were different from the scientific ones?
> Amar: At the first instant I thought you were wrong.
> Researcher: You thought I was wrong?
> Amar: Yes, because when a thing is taught to a child in primary school then he takes it as a right thing, and then when he grows up and someone tells him it's wrong and then he says it's not wrong, my teacher taught me that (Indian male).

However, when questioned further, such students generally admitted that their alternative views may not have derived directly from what their teacher stated, but rather their own interpretation of this.

Others claimed to be 'happy' when they found out their views were 'wrong' because they felt it was important to have the correct scientific view if they were going to teach science themselves.

> Researcher: OK so you said you had one idea and then when we discussed it and you discovered that the scientific idea was different from yours?
> Laisani: Yeah.
> Researcher: How did you feel about that?
> Laisani: I feel happy because the idea that I think is different and it's wrong from the scientific idea.
> Researcher: You felt happy?
> Laisani: Yes because it improves my knowledge of science (Fijian female).

This positivist view of scientific knowledge being true remained with all the students interviewed, despite the initial discussion of different ways of viewing the world which had taken place at the beginning of the experimental treatment. Given the beliefs on the nature of science expressed by students interviewed during the Elicitation Phase this was understandable. These views indicated that the students were not cognisant with the concept of science as 'a way of knowing' but in general viewed scientific knowledge in absolutist terms. This view of science would possibly sit more comfortably with students growing up in a country such as Fiji where fundamental religious and political views were prevalent.

Although rare, occasionally a student was able to identify that conceptual change had taken place and could link this to a particular learning experience.

Researcher: When sugar dissolves does it change into water?
Amar: No it mixes with water.
Researcher: Did you ever think it changed to water?
Amar: Yes.
Researcher: What made you change your view?
Amar: Partly the coloured solution...because the particles of potassium permanganate...that one the colour so we could see it didn't change to water (Indian male).

Amar was referring to an analogy in which the visually supported solution of potassium permanganate crystals was used to target the alternate conception that white sugar changes into water when it dissolves.

Certainly, most students claimed that they had become more aware of their alternative conceptions as a result of the open discussion of preconceptions, and a number were aware of having undergone conceptual change. None of these students felt that this change of view had been detrimental to his/her confidence and in fact most found the question surprising.

7.5.3 Concept mapping at the midpoint of the experimental treatment

The strategy of using concept mapping in the experimental treatment had a dual purpose. It was intended for use as a teaching tool and also afforded the researcher another means by which to monitor the progress of the experimental group during the treatment. Prior to commencement of the treatment, the subjects had been given instruction in drawing concept maps and then asked to produce initial concept maps on matter and how it changes. This activity was completed by five self-appointed groups in which the subjects discussed their ideas while constructing the maps. These were then submitted to the researcher.

At the end of week three, the mid point of the experimental treatment, the students were asked to repeat this exercise, drawing on their new knowledge of matter. Once the second set of maps were completed, the pre-instruction concept maps were returned to the groups for comparison. In particular they were asked to examine the new maps for the inclusion of new concepts and conceptual links.

Figure 7.1 provides an example of a concept map constructed prior to the start of the treatment by four Fijian students. This was typical of the initial concept maps the groups produced which were largely similar in construction, each with a dominant triangular structure. It transpired that these bore a striking resemblance to a figure which the students had encountered during their high school science in Form 3 (Year 9) which also employed a triangular format and incorporated diagrammatic representations of matter at the particulate level (Figure 7.2). The recollection of this diagram appeared to exert a strong influence on most of the students' initial constructions.

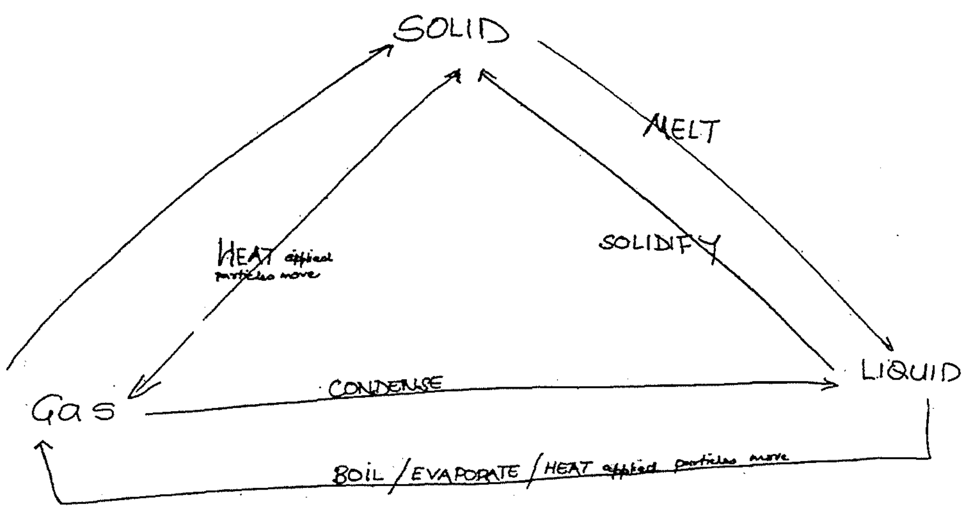


Figure 7.1. An example from the initial concept maps constructed by the students prior to instruction.

The initial concept maps produced by the students confirmed some of the findings from the interviews and SCS. The macro-level connections between the different phases are generally represented appropriately. However, although each group included the concept of particles in some aspect of their respective maps, the relationship between energy and particles was never represented appropriately. In the map shown in Figure 7.1, for example, the three states of matter are linked using an inconsistent variety of energy and process connections, and although particles are included it is not stated explicitly that particles gain or lose energy during phase change. All of the initial maps made reference only to the spatial distribution of particles rather than their behavioural relationship to energy inputs and outputs.

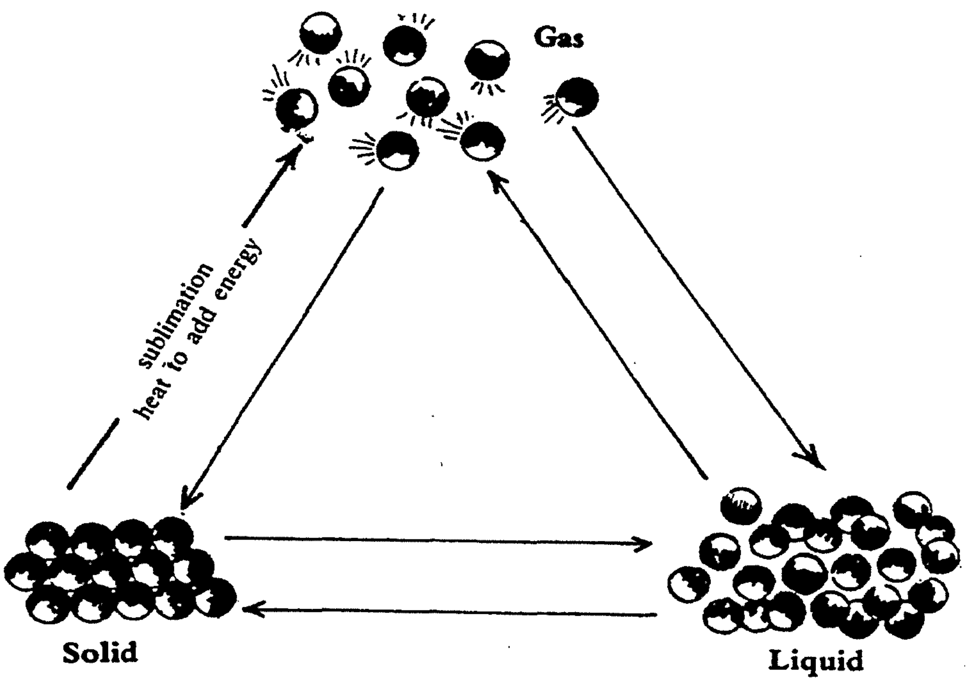


Figure 7.2. The 'States of Matter' diagram from the Form 3 Basic Science Pupil Book page 20. (Fiji Ministry of Education, 1982).

Figure 7.3 provides an example of a mid-treatment concept map constructed by the same group of four Fijian students who produced the initial map shown in Figure 7.1. The mid-treatment map shows that the triangular model which dominated the initial concept maps was no longer present. This was also true for other groups who took part. There was also an increase in the number of concepts and links included in the latter maps across all of the groups. On this occasion the concept of energy gain or loss between phases has been incorporated, but had not been applied explicitly to particle behaviour. In fact once again the qualitative data presented on particles relate to their spatial distribution.

However, all of the mid-treatment maps incorporated the concept of energy gain and loss, with three maps linking this correctly to particle behaviour and phase change. This was the most obvious evidence of knowledge construction provided by the mapping exercise. It appeared that during the first three weeks of the experimental treatment the notion of particle energy gain and loss with its subsequent impact on particle behaviour and ultimately matter itself had been constructed by many of the students.

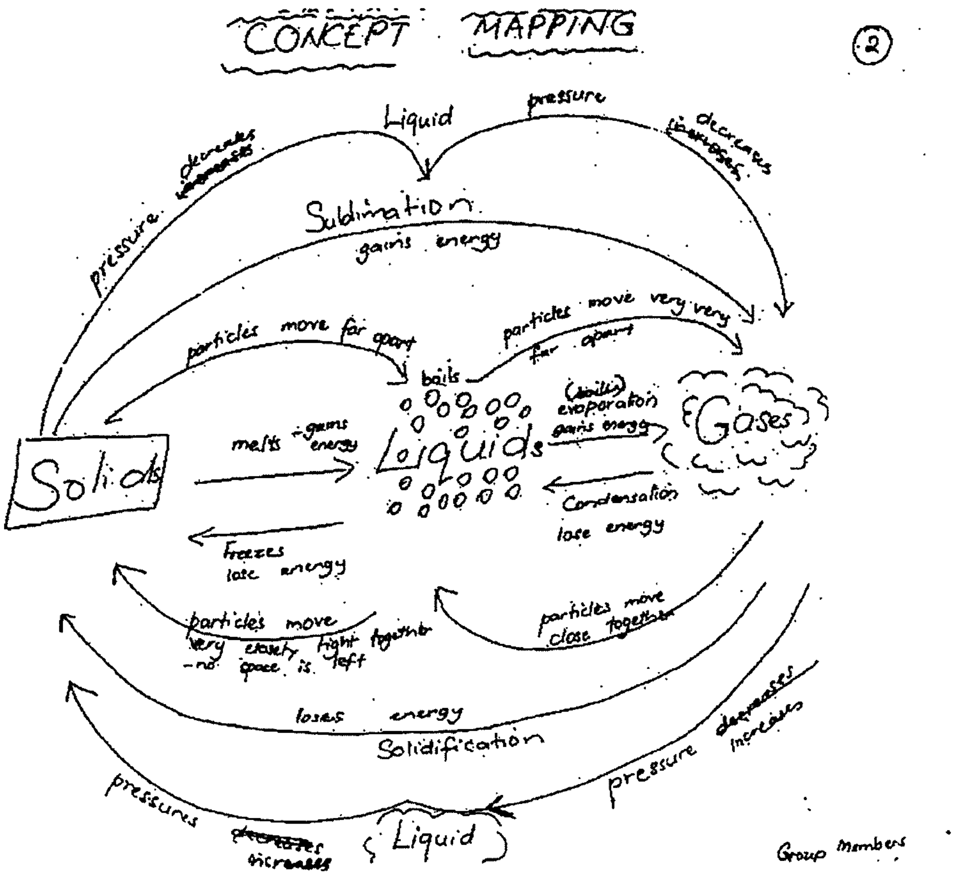


Figure 7.3. Concept map constructed after three weeks of the experimental treatment.

The opportunity to produce a final concept map at the end of the course did not arise due to constraints of time. However, one Fijian male student did voluntarily produce a concept map of pressure. This map was more complex than those received previously and contained fewer naive connections. The student claimed he had enjoyed the experience of concept mapping and wished to pursue it.

No attempt was made to quantify and score the initial and mid-treatment concept maps as this was not considered to be appropriate, especially as the major function of the concept mapping exercises was instruction. Although they provided some insight into the students' conceptual development during the experimental treatment, this insight was clearly limited. Perhaps the most encouraging outcome of the use of concept maps in monitoring progress was the revelation that the majority of groups were beginning to construct some understanding of the relationship between energy and particles, a concept critical to the domain of matter and how it changes.

While many of the students interviewed understood how concept maps could be used to help gauge their understanding of a topic, this strategy received a mixed response with about half of those interviewed stating that they found it of benefit.

> Salote: It's (concept mapping)...it was rather difficult in the first place...the one we did at the end of last semester...comparing it with the one we did more recently...like I've found that I've made many more connections this semester than I've written last semester...that shows me that I have learnt more this semester (Fijian female).

> Researcher: Did you find it (concept mapping) an interesting idea?
> Luisa: It was interesting...first we quarrelled with my friends about what would happen...the relationships between those...those...what?
> Researcher: Concepts.
> Luisa: Those concepts...but it was interesting finding the relationship and how they would interact (Fijian female).

The fact that Luisa mentioned that her group quarrelled about the relationships between concepts suggests that in this instance the activity was stimulating higher level thinking and an attempt was being made to construct a concept map which properly represented the changes in matter. This would suggest that, for this group at least, concept mapping represented a positive learning experience.

However, other students found the concept mapping procedure difficult and of little value to them, particularly those who failed to understand the potential learning benefits of this strategy.

> Researcher: How did you find drawing the concept maps?
> Milika: I found that difficult.
> Researcher: Has any other teacher done that with you?
> Milika: No.
> Researcher: Did you understand why I was asking you to do it?
> Milika: No (Fijian female).

> Researcher: Can you explain to me the idea behind drawing a concept map?
> Anil: I mean they will be using arrows and the arrows will going to the right place and maybe there's misunderstanding and they'll put it another way.
> Researcher: How did you find the concept mapping?
> Anil: It was quite confusing.
> Researcher: Why was it confusing?

> Anil: When it has many links it's like eh many arrows going to one place and some having just one or two...I didn't find it very useful...I didn't like it (Indian male).

As mentioned previously, although there was evidence from some of the sequential concept maps that students were producing more links between appropriate concepts, many found this strategy difficult and of limited value to them. Although initial training had been given, because of time constraints it was not possible to allow the students to undertake sufficient practice to improve their skills effectively. However, the responses of a number of students did suggest that with perseverance this strategy could prove to be more universally effective as evidenced by these comments.

> Researcher: How did you find the idea of concept mapping?
> Mereani: It's...it was rather hard in the first place...the one we did last semester...but then doing it this semester you know there were many more connections. Like we can connect this with that and that with that like...
> Researcher: So you felt you could make...
> Mereani: Yes more connections.
> Researcher: Did you understand the reasoning behind concept maps and how they might help in your learning of science?
> Mereani: I found out that I've made many more connections this semester than in the concept map I've written last semester...that shows me that...I think that I have learnt more this semester like.

7.5.4 Lesson 6 - Pressure

The final examples of group discourse are taken from the last lesson of the experimental treatment, which dealt with the topic of gaseous pressure. By this stage the students had gained more experience working within a collaborative format. Prior to embarking on group work, there had been a general discussion to draw out the underlying particulate basis to gas pressure and those factors which cause the pressure of a gas to vary. In this first activity the students were asked to invert a beaker over a floating cork and then submerge it.

7.5.4.1 Activity 1 - Inverted beaker over cork

(Romila, Urmila and Mohini are Indian females; Sanjay is Indian male)

1. Researcher: What happens?
2. Romila: No we were talking about that.
3. Researcher: So why does the...why do you get this effect.?

4. Urmila: When we submerge this beaker then there is no air so pressure is created when we push it down...
5. Researcher: What do you mean 'there's no air'...no air where?.
6. Urmila: No air in the beaker...no?
7. Mohini: There is air.
8. Urmila: Oh there's air present in the beaker?
9. Romila: Yes because when you lift it (tilt it) the bubbles come out...no?
10. Urmila: Yeah when we lift it the bubbles come out.
11. Researcher: So what is this activity showing?
12. Urmila: The air is still present inside.
13. Researcher: Yeah.
14. Mohini: And it also does not allow the water to go inside.
15. Researcher: What is it that doesn't allow the water to go inside.
16. Urmila & Romila: The air.
17. Researcher: So how does the air prevent the water from going inside?
18. Urmila: Air has particles so the particles don't have any gaps.
19. Romila: No there is gaps between the air particles.
20. Researcher: What are those particles doing?
21. Mohini: Moving.
22. Urmila: Colliding.
23. Researcher: Moving very fast?
24. Urmila: Yeah.
25. Researcher: And each time they collide with the water...
26. Urmila: They create pressure.
27. Researcher: Therefore...don't forget you're not talking about 2 or 3 air particles in here you're talking about many millions...yeah...that are flying around and that creates the pressure.
28. Urmila: Yeah.

This activity was intended to demonstrate that air occupied space and exerted pressure. In discussing the activity Urmila displays the alternative conception that there is no air in the beaker (4). However, her colleague Romila is able to share her understanding of this concept to demonstrate the presence of air inside the beaker (9-12). This sharing of information appeared to help Urmila construct a better understanding of the scientific view by lowering the status of her alternative conception.

In order to proceed from a macro level view of air pressure to a particulate view, scaffolding was required. In this instance it took the form of a series of questions which probed further into the students' understanding. In moving to a particle model, a further alternative conception was revealed by Urmila (18), but was quickly challenged by Romila (19). Further scaffolding (20) appeared to induce the recollection of one of the key concepts discussed at the beginning of the lesson, that gas particle collisions result in pressure being exerted. In previous lessons subjects had often ignored conceptual information provided to help them construct meaning from the activities. The incorporation of the concept of particle collision meant that this group were able to construct an explanation of air pressure which approached the scientific view. The activity which followed demonstrated how this same group coped when there was no scaffolding available.

7.5.4.2 Activity 2 - Model Lung

1. Urmila: What about the model lung.
2. Romila: Model of lung.
3. Mohini: What happens?
4. Romila: When the diaphragm or the plastic has been pulled outside the balloon expands.
5. Urmila: So what's this showing?
6. Romila: It shows that...I don't know.
7. Urmila: When the rod is pulled...the tag is pulled the balloon...eh what happens when the tag is pulled...the balloon...
8. Mohini: Expands.
9. Romila Swells.
10. Mohini: Expands and contracts.
11. Urmila: Ah right the balloon expands...
12. Mohini: When the plastic is being pulled out.
13. Urmila: And when it is being pushed in it contracts.
14. Romila: Does it happen when you put your finger on top of the rod (glass tubing)?
15. Urmila: No eh?...Why does it happen?
16. Romila: Mohini why does it happen?
17. Mohini: This works like a lung, similar to the lung model...so you can see when we breathe in...
18. Romila: When we breathe in air is being pushed no...
19. Mohini: Our lungs is filled with air right...and the diaphragm moves outwards...outwards. When we breathe out the diaphragm moves inwards and our lungs is contracts like there's no air left in them.
20. Urmila: That's all?
21. Romila: Yes.

In this case, with the absence of any scaffolding, the group made a rather weak attempt to construct an explanation. There was no attempt to incorporate particle theory into their explanation despite having used it in the previous activity. In fact, the term pressure itself was never introduced to their discussion. Instead Mohini made a comparison with the human lungs (19) with only a weak attempt at explaining the mechanism, before they moved on to the next activity. Clearly, without scaffolding, this activity had been of little value to the group.

A different group comprising three Fijian female students were also recorded discussing this activity.

1. Luisa: (Reading) 'Using the model lung pull down the plastic sheet by holding the tag...record and explain your observations'...That's a model lung?
2. Mereani: Yes...There's expansion and there is contraction...when you pull the balloon expands and when you push the balloon contracts.
3. Luisa: Contracts.
4. Lanieta: There's more concentration of air...
5. Mereani: No we use pressure...when we pull what are we doing?
6. Luisa: I think the outside pressure is more than the pressure inside...inside the bottle...so when we pull the air from outside are being forced inside...so it has...
7. Mereani: Leading to the expansion of the balloon.
8. Luisa: And when we push we're forcing the air inside to get out again.
9. Mereani: No it cannot get out just like that.
10. Lanieta: See because the thing is fixed onto the balloon eh.
11. Mereani: OK the explanation of the expansion is that...the expansion of the balloon is due to the atmospheric pressure outside yeah.
12. Luisa: Yeah.
13. Mereani: Like there's more pressure outside...when we pull this down...man...I just don't know what happens to the pressure inside there.
14. Mereani: OK first of all is there any pressure inside the bottle? Inside this...yes?
15. Luisa: Yes.
16. Mereani: That means the amount of pressure in here is smaller than the amount of air pressure outside.
17. Luisa: Yes outside.
18. Mereani: OK so when we pull it...air flows from high pressure to low pressure...so...pressure outside pushes air inside therefore leading to the expansion of this.
19. Lanieta: Can I try?
20. Mereani: Sure.
21. Researcher: That sounded good tell me again.
22. Mereani: (Laughs) Like we were just explaining on why this balloon expands when we pull down the plastic.
23. Researcher: Right.
24. Mereani: Like the pressure inside this bottle is less than the pressure outside in the atmosphere.
25. Researcher: That's exactly right. What have you done to the volume when you pull this down ...what do you do to the volume?
26. Mereani & Luisa: You increase the volume.
27. Mereani: When we increase the volume we decrease the pressure...there is less collisions.
28. Luisa: When we increase the volume?
29. Mereani: Yes...let's see when we increase the volume...we decrease the pressure inside the bottle...so there is more pressure outside...see, so air is forced inside...but when you push the plastic up we are decreasing the volume but we are increasing the pressure inside the bottle...therefore the air inside the balloon is forced out again....you get it?
30. Luisa: Yes.

31.Mereani: All right!
32.Luisa: That's number 2 eh?
33.Lanieta: What's this called.
34.Mereani: The tag...when we pull the tag there's more volume you know? Like we're increasing the volume when we pull the tag....and when we increase the volume we're decreasing the pressure inside the bottle.
35.Lanieta: Oh yeah therefore air from outside rush into...
36.Mereani: Yes...see air from outside rushes in...it's pushed, it's pushed because the atmosphere...I mean because the pressure outside is more than the pressure inside the bottle.
37.Lanieta: Inside is more eh?
38.Mereani: Pressure outside!
39.Lanieta: Oh yeah.
40.Mereani: And when we push just the exact opposite eh...there's less volume, there's an increase in pressure air inside the balloon is forced out.

In this case Mereani took the dominant role within the group and offered the greatest number of assertions. In the main Luisa and Lanieta simply agreed with these. However, Luisa was the first to relate the expansion and contraction of the balloon to differential pressure (6). The introduction of the concept of volume to the discussion by the lecturer was immediately taken up by Mereani who indicated that not only did she understand the relationship between volume and pressure, but she could explain it at a particulate level. Although Mereani tended to dominate the group, she was concerned that her colleagues also understood the concepts in question (29-31). Her understanding was also such that the use of the alternative conception of 'sucking' was never introduced into the discussion.

Once again this episode demonstrates the importance of scaffolding in collaborative group work. The introduction of the concept of volume by the researcher (25) allowed the discourse to proceed into a new conceptual area which might otherwise not have been explored by the subjects. Furthermore, as with the previous group, these subjects were now utilising ideas drawn out from the initial class discussion in their knowledge construction. For example, Mereani introduced the notion of fewer particulate collisions with increased volume to explain the reduction of pressure within the bottle (27). As mentioned before, this conception had been discussed and demonstrated at the start of the lesson. However, this group of Fijian females were clearly more determined to construct a satisfactory explanation than the previous group of Indian females on the same activity. Ultimately, they were able to construct a scientifically acceptable model which was underpinned by the appropriate incorporation of concepts from Kinetic Theory.

Mereani proved to be an interesting subject as she came to the course with a limited science background, having dropped school science at the end of Form 4 (Year 10) when it ceased to be compulsory. However, once she had constructed an understanding of the energy/particle relationship in the initial lesson, she appeared to develop a determination to apply this concept to the remaining problems. Thus during the episode on boiling water (p. 280) she insisted that her partner Sheetal, who had completed Form 7 (Year 13) chemistry and physics, explain the problem of the bubbles in boiling water in terms of energy and particles. Later in the episode involving pressure (p. 293) she assumed the responsibility of mentor for her group, and peer tutored them until she was satisfied they had constructed a better understanding of this concept. Mereani's conceptual development in the domain of matter throughout the course of the research will be discussed in more detail later in this chapter.

Overall, in the conceptual domain of pressure, the experimental group achieved a mean student gainscore of 1.38, which compared with a gain of only 0.13 for the control group on the same eleven items. This was despite the control group engaging in the same activities, but in a much more structured context and without reference to analogies or models. Furthermore, the three Fijian females, Luisa, Meriani and Lanieta, who featured in the final episode of discourse produced a mean gain of 3.67. This was markedly higher than the experimental group average, and may have reflected their approach to the collaborative group work which displayed not only great perseverance but also a concern that all group members had gained a satisfactory understanding of the concepts discussed.

As a learning forum, collaborative group work was generally perceived as beneficial. The students claimed that they found it helpful to share their ideas when attempting to construct explanations for the outcomes of the practical activities. Fijian students readily connected this kind of learning experience to their cultural background.

Researcher: Do you like working in groups or do you prefer to work individually?
Merelesita: I like working in groups.
Researcher: Why is that?
Merelesita: So that I can share the ideas, I can eh share the ideas with others and the others share ideas with me.
Researcher: Did you think this was a suitable way for Fijians to work?
Merelesita: Yes.
Researcher: Why would that be?
Merelesita: Because Fijians rely on each other and eh they are very good in sharing (Fijian female).

Sofia: We share our knowledge...our skills and we are never scared of asking one another questions...any type of question (Fijian female).

Indian students were rather more ambivalent about group work. Most perceived that their society was more competitive and individualistic than that of Fijians. But views differed as to the merits of collaborative group work.

Ramesh: Indians they usually work individually.
Researcher: Why is that?
Ramesh: I think because of their family background.
Researcher: Could you say a bit more about that?
Ramesh: Because from young they are not mixing around with their peers. For example Fijian people they stay in groups in their villages...all of them mix together, but for Indians that thing's not happen...if one house is there, another house is far away, they don't mix.
Researcher: So you're saying as a child you don't mix much with your peers?
Ramesh: Yes, they just want to challenge...if that one is first, they want to be first, they don't want to help...that's the problem.
Researcher: Well I did make you work in groups, did you personally like that or would you have preferred to work as an individual?
Ramesh: Yes I think I prefer individual (Indian male).

However the majority of Indian students viewed group work in a positive light.

Nisha: I think working in groups is much better...
Preeti: Because we get the views of everybody.
Nisha: Yeah we are able to help each other in understanding some things.
Researcher: So you found it...did everyone participate in your groups...I think you were together sometimes?
Nisha: Yeah all the girls all the girls together...
Researcher: Generally did they participate?
Nisha: Yes, girls are usually co-operative (both Indian females)

One student was able to reconcile competitive instincts with a collaborative group learning environment.

> Sanjiv: Even if you want to compete, group work can help...if I want to compete and know more then I have to involve myself into a discussion with other people in my group (Indian male)

However, group work was not viewed as a panacea even by all of the Fijian students, as a small number stated that, although they found it beneficial, they were critical of the fact that not all their colleagues participated or took things seriously.

In the foregoing sections a reflection of the activities completed by the experimental and control groups during their respective treatments have been discussed. These reflections are illustrative of the fact that in all five conceptual domains the experimental group out-performed the control group in terms of mean student gainscores. Change of state, conservation of matter and pressure have already been discussed, but a similar outcome was achieved for the domain of solubility with mean student gainscores of 0.96 for the experimental group and 0.13 for the control group on five items. Similarly, the domain of heat produced scores of 1.08 and -0.17 respectively on five items.

These data were further analysed to allow for the variation in the number of items within each domain, by calculating the mean student gainscore per item. This analysis showed that the experimental group achieved the largest gains in the domains of heat and conservation of matter with values of 0.25 and 0.23 respectively, while solubility, change of state and pressure produced values of 0.16, 0.13 and 0.11 respectively.

While no claims can be made about the comparative difficulty of the items within each domain, it might be conjectured that the treatment was more effective in developing improved understanding in the conceptual domains of matter conservation and heat than the other domains covered. The students' earlier comments about the models and analogies may offer some clues to this apparent difference. A number of students claimed that these learning experiences allowed them to see that during heating and state change the physical characteristics of the particles remained the same. Thus they became aware that the particles did not enlarge, contract or disappear and their numbers remained constant. A better grasp of these concepts would certainly have improved their understanding of conservation and heat, possibly to a greater extent than in the other domains examined. However, this inference is extremely tentative and would require further investigation before more substantive claims could be made.

7.6 Other data from the monitoring and evaluation of the intervention

The following sections deal with, amongst other things, one of the strategies employed in the experimental treatment but not discussed previously, namely the explicit introduction of the students to a constructivist view of learning. A further section records how the students from the experimental group compared and contrasted their experience of previous science instruction with that received during the intervention. This was of particular significance, as it was important to determine if the students perceived these modes of instruction as different, and could articulate and justify which, if any, they found more effective.

Finally, the views of the normal science lecturer are presented, as these offer a further perspective on the effectiveness of the teaching intervention from an individual with considerable experience in the teaching of science at various levels in Fiji. Together with the data presented earlier, these final sections help to complete a comprehensive evaluation of the teaching intervention by drawing on information from a number of different perspectives.

7.6.1 Introduction to constructivism

An introduction to a constructivist view of learning was one of the first strategies to which the experimental group was exposed. As mentioned previously this was intended to help the students reflect on their own learning. However, the response to this strategy proved to be rather disappointing. Most students claimed they had no recollection of this theory despite the class having discussed it in advance of the teaching experiment. Some confused it with analogies, and even after considerable prompting about the ideas children bring with them to science lessons only a few could amplify this further.

> Researcher: At the very beginning when we discussed something called constructivism, did you understand that?

Mereani: Yes that's all about analogies and all.
Researcher: No before the analogies I mentioned that we often have ideas about science before we...
Mereani: Oh before we even get into a science lesson.
Researcher: Yes.
Mereani: Like teachers they sometimes think that students come without any knowledge of science but actually they do have some.
Researcher: Did you understand that idea?
Mereani: Yeah because like although they have conceptions about science mostly they are the wrong ones...for example like you say your mum tells you not to sit next to the fire because your spine will melt (laughs) (Fijian female).

Given the generally poor recall of the constructivist view of learning it seems unlikely that there was the kind of metacognitive development in terms of better understanding of their own learning process that was claimed by Summers and Kruger (1994). However, while Summers and Kruger were working with in-service primary school teachers who could probably relate Constructivist Theory to their own teaching experiences, the pre-service teachers in Fiji had very little teaching experience to draw upon. Furthermore, these authors may have stressed their theoretical framework more consistently throughout their training program than was the case in Fiji.

7.6.2 Contrast with school and the college science programs

Many students who took part in the final interviews reported that they had been taught science at school in an environment which offered them little opportunity to do practical work.

Researcher: When you were at school learning Basic Science did you get a chance to do much practical work?
Sanjesh: Depends...but mostly the teacher just writes the answer.
Researcher: So the teacher wrote the answers on the board?
Sanjesh: If they were not able to cover the syllabus then they just write the answer on the board and we learn it.
Researcher: Even if you don't understand it?
Sanjesh: Yes (laughs) (Indian male).

Some contrasted their experiences of school science with the experimental treatment conducted at the college.

Researcher: Was the teaching you received during our session similar or different from what you experienced in school?
Tevita: It's different.
Researcher: In what way was it different?
Tevita: At school we just had to follow the exercise books...and most of the time we didn't do the experiment.

Researcher: So did you see the experiments at all, or just in the book?
Tevita: Sometimes the teacher would just demonstrate the experiment and then we just had to...the main requirement was for us just to fill up the books, whether we knew what was happening or not (laughs)...or we didn't understand...(Fijian male).

Seremaia: This was really different from school.
Researcher: In what way?
Seremaia: In school most of the time you didn't do experiments...the teacher tells us what the result will be like so we just sit down there and absorb everything from the teacher.
Researcher: Was that because of lack of equipment?
Seremaia: Not really, the teachers could have made more effort...improvised.
Researcher: Did you perform any experiments?
Seremaia: If I'm correct maybe only one.
Researcher: In one year of Form 7 (Year 13)?
Seremaia: In one year yeah (Fijian male).

Even when students reported that there had been practical experiences provided, some were critical of the way in which these practical activities had been conducted.

Mereani: Actually the science that I was taking up until Form 4 (Year 10) most of the experiments were done by the teachers so it was just a demonstration or...like the students get to do the experiments and find out things for themselves...but even if they are to do an experiment...like the answer they would have known before they do the experiment like they will be told what they will find out and all...especially about that egg thing (egg and bottle demonstration)...she went like this, 'you know the egg will go inside', then she gave us the experiment to do, but then there was no point in doing the experiment because she had already told us (Fijian female).

Although most of the subjects contrasted the experimental treatment favourably with their previous school experience of science, this was not true of all the subjects.

Nisha: It (the experimental treatment) was quite similar to my school experience...like the groupings and the distribution of materials and all those things...but sometimes in our high school we used to have a bit less practical (Indian female).

7.6.3 The views of the college lecturer in science education

The science education lecturer who normally taught all of the second year science classes acted as an observer to both the control and experimental treatments. Her views on the treatments were sought informally throughout the teaching experiments and she was interviewed more formally on two separate occasions. Some of her comments on the research are reported below.

The lecturer confirmed that the control sessions were in keeping with the normal practice at the college and that there was a distinct difference between the treatments.

> Researcher: Would you say that there was any difference between the approach that was used with this group (experimental treatment) and the approach I used with the control group.
> Lecturer: I can't really say that they are similar...I can see that there is a difference in...eh the way that you were carrying out the experimental group and the other group, the control group. I can relate the control group to what I am doing with the other groups (laughs). I have seen that your experiment group is a lot more exciting...you know like it's something new, not that I'm saying it just because you're here, even what the students are telling me they find it.

When asked about specific strategies employed within the experimental treatment, the lecturer was quite positive.

> Researcher: Did you have any comments about what you saw during that first experimental lessons that I took...don't be frightened to be critical.
> Lecturer: (laughs)
> Researcher: Mainly I was interested in giving them (the students) a few simple problems in groups and seeing if they could work on those, they weren't difficult really, but I wanted to see if they could use what science knowledge they had to solve them.
> Lecturer: Yeah that was very interesting, at the same time it brought out a few things that I just discovered that day...em you know like the experiments that you set were quite simple for them to follow, and em at the same time while I was observing them I could see those who may have started off with a wrong idea...just by doing that...discussing it in groups eh...I could see if they have any confusion before...I think at the end of that lesson that confusion might have been removed...and the other thing is eh I like the questions asked because it helps them to think. Even one of them came to me and told me, 'You know Mrs. Kepa, now I understand...what she says she understands was when they heat acetone...like to her she said she always thought there's extra something added you know...to me that's interesting, because I never thought that anyone would have come up with that idea. She said I always think that when you heat something there were extra particles coming in, instead of them increasing the space between them.' To me that is something satisfactory...

The lecturer was also particularly impressed by the use of the Kinetic Theory model which she felt was much more effective than the static two dimensional diagrams presented in the text. In fact this was one innovation she adopted with her own classes who produced an improvised version of this model which the researcher had constructed with the experimental group.

When asked whether she felt the students arrived at the college with sufficient science content knowledge to teach primary science, and in particular classes 7 and 8, the lecturer commented that this was probably assuming too much.

> Lecturer: When they asked me to come here I had to talk to a couple of head teachers and see how well our students coming out of here teach science. Because to me that is a big responsibility eh. When I asked them what do you want me to go and do they said teach them to teach Basic Science. So one of the head teachers told me that she's disappointed with the way they are teaching Basic Science...I mean you can presume too much...I don't think these kids with whatever basic knowledge that they had in science I don't think that's enough for them to be able to be em let's say em ground work for teaching Basic Science in primary schools if the interest are not there.

Although the lecturer had never been introduced to the term 'constructivism', she was aware that the students did hold alternative conceptions in science.

> Researcher: What about their actual understanding of the content itself...is it pretty variable?
> Lecturer: Yeah I think there was a lot of misconceptions like eh let's say for example now they talk about eh particles expanding and contracting as the major reason behind how matter expand and contract. So to me if they have that misconception it's not something that they just learn here, it has been taught in primary schools, even secondary schools.

The lecturer claimed she was trying to implement some changes. Rather than going through the Basic Science books lesson by lesson, which had been the practice before her arrival, she now grouped the lessons together in terms of concepts even if they were not presented consecutively in the book. In fact she suggested that, in the future, she might be not using the Teacher's Guide in her teaching.

> I think they do well if they understand what they are doing...they are at an advantage over those who have only used the text books because I have realised that em this year I discouraged them, I hardly give them the Teacher's Guide, because the Teacher's Guide has all the answers to the problems in the Pupil Book and to me it's like spoon feeding...So I have all the objectives typed out, so I'll just photo copy it. I feel if there is any misunderstanding now it's best to deal with it here than there. The less you depend on the text book the better.

Despite this final sentence, the statement as a whole implied that the lecturer was intending to continue using the Pupil Book. This proved to be the case for, although the lecturer made favourable comments about the experimental treatment in which neither the Basic Science Teacher's Guide nor Pupil Book were ever used, she continued to employ the Pupil Book as the focus of her own lessons. This may have been due to a lack of confidence in her own ability to employ the pedagogy involved in the experimental treatment, or she may have been put off by the extra preparation time involved.

The key points which emerged from the discussions with the science education lecturer were her acknowledgement that the control and experimental treatments were different, as this was crucial to the study. Furthermore, it was clear that she appeared to be aware of some of the problems that the experimental treatment was designed to address, but had no strategies for dealing with these given her traditional Fiji experience.

7.6.4 Summary

This section of the Evaluation Phase has presented data from a variety of sources to account for the marked difference in performance between the experimental and control groups on the post-test. Clearly students in the control group were exposed to a treatment which they themselves recognised as lacking sufficient depth to improve their content knowledge significantly. Furthermore, although the learning environment included group work sessions, the opportunities to construct knowledge socially seemed to be stifled by a strict adherence to the text. Many of the strategies employed within the experimental treatment, for example the use of analogies, proved to be entirely novel to the pre-service teachers, and certainly neither the students nor science education lecturers were familiar with constructivism. Thus this overall approach was highly original in the context of the teachers' college.

The episodes of discourse which evolved during the collaborative group work suggest that this approach to learning offers considerable potential amongst pre-service primary teachers in Fiji regardless of ethnicity. There were strong indications that, supplied with the appropriate information, students would work together and share information in an attempt to construct meaning regardless of cultural background. Clearly access to suitable scaffolding was a key element in this process. There were, however, certain problems associated with this approach. Not all of the individuals co-operated and there was a tendency for some male students from both ethnic groups to leave the female members to work on the problems before asking for the explanation, having had a minimal input. Although the class was not excessively large for this type of approach, it was still difficult for the lecturer to get around all of the groups. In addition the groups themselves seemed reluctant to request assistance. These two factors made effective scaffolding difficult. Furthermore, the information which came out of the initial class discussion was sometimes misinterpreted or else some of the groups disregarded it and made no effort to apply it to the problems presented. Nevertheless, this format appeared to provide much greater opportunities for students to engage in knowledge construction and higher level thinking.

It was particularly encouraging that the majority of students interviewed were able to identify those strategies which they had found most beneficial and to articulate why this was the case. Furthermore, they appeared to be quite candid in their responses as they were not afraid to mention those strategies which they personally found to be of little benefit.

Finally, it should be pointed out that three students in the experimental group (one Indian male, one Fijian male and one Fijian female) regressed in terms of their post-test scores. It was clearly of interest to attempt to ascertain why this occurred and, in particular, if this was due to the strategies employed. However, they all claimed their performance was not related to the teaching strategies. The Fijian female and Indian male claimed they had completed Form 7 science and felt their science was competent. Consequently they had 'coasted' during the treatment leaving most of the work to their friends. The Fijian male who had suffered the largest regression claimed that he found the researcher's accent difficult to follow.

7.7 Further analysis of post-intervention data

The final component of the Evaluation Phase involved a qualitative investigation of the students' understanding of matter and how it changes. As mentioned in chapter 6, tests or surveys have certain inherent weaknesses when used to diagnose alternative conceptions. Most notable of these are the stimuli which the statements provide for the subjects. These may act as a trigger to memory. Since interviews require the students to come up with their own explanations, it was deemed appropriate to interview members of the experimental and control groups post-intervention to determine if their qualitative responses were consistent with those provided in the post-test. In fact, since some students from both groups had also been interviewed prior to the teaching experiment, it was possible to integrate all of these data and construct approximate cognitive profiles using the quantitative and qualitative data available.

In total, fifteen experimental and six control subjects were interviewed during this component of the research. The interviews involved revisiting IAI cards 1, 2, 3, 6 and 8, along with two POE activities, the air thermometer and the model lung, although, with some subjects, time constraints did not permit all of these stimulus materials to be discussed. Interviews took place between two and four weeks after the intervention. It was considered that these cards and activities covered a sufficient range of concepts to provide an adequate qualitative check of the students' understanding. The data are presented as a series of case reports which provide an illustration of changes in some students' conceptual understanding throughout the research project. Where interview data have been used, scientific and alternative conceptions have been coded by applying the coding system developed from the CPI.

7.7.1 Case reports for some experimental group subjects

7.7.1.2 Rekha (Indian female)

Rekha had not pursued science after Form 4 (Year 10), which is the final compulsory year. She claimed that she had not enjoyed science due to what she perceived as poor teaching. Moreover she implied a lack of confidence in her ability to teach science at the upper primary level (**I** represents the interviewer in all the episodes which follow).

> I: Next year if you were given Class 7 or 8 to teach, would you feel confident about teaching those classes science?
> Rekha: I'd face some major difficulties...I'd have to take assistance from other teachers maybe...I'll have to be prepared before I go to the class to teach.
> I: Why would you have to take assistance from other teachers?

Rekha: Because I think I'm not that good at science...it's my opinion.

Certainly her pre-intervention interview revealed clear weaknesses in her conceptual understanding in this domain of science. For example:

Card 1 Melting ice cubes

Pre-intervention response
I: I'll take you through these cards and you try and explain as scientifically as you can what's happening. What's happening here?
Rekha: A glass of ice cubes...it's being put in the...the cubes are being put in the glass...then after 5 minutes it's melting away...then it has melted and then it has condensed I think...condensation has taken place.
I: How does that process of melting take place?
Rekha: It's the heat from the atmosphere. **A.1.1**
I: And what is that doing?
Rekha: It's melting the cubes away...they are no longer in the freezer.
I: How would you explain scientifically how melting takes place?
Rekha: I don't have much idea about it.
I: Do you know how the heat actually makes the ice melt?
Rekha: ...No I'm not sure.
I: OK...this outside...you mentioned there was some condensation, where do you think that came from?
Rekha: This is the glass and eh as it melted the...I'm not quite clear with it...I won't be able to explain it.
I: Well if I said to you how does that water get there, could you tell me?
Rekha: Is that the condensation part?
I: Yes.
Rekha: The glass has maybe absorbed it...**A.2.2**
I: From where?
Rekha: I don't think I would be able to explain it.

At this stage Rekha appeared to hold very few conceptions either alternative or scientific about either melting or condensation. She was aware that the change from solid to liquid required heat energy **(A.1.1)** but was unable to apply particle theory to explain this further. Similarly, condensation could not be explained and Rekha was apparently unaware of its origins at this stage.

Rekha's performance on the four pre-test items which related directly to Card 1 reflected the limited understanding exhibited in the interview, with only one correct response (item 3). This however, indicated that she was now aware that condensation derived from the atmosphere, a response perhaps stimulated by the item statement.

Her post-test performance showed a marked improvement, with correct responses and appropriate justification to all of the same four items. This suggested some improvement in understanding may have occurred as a result of instruction. The post-intervention interview was an attempt to triangulate these quantitative findings.

Post-intervention response

I: Could you explain this first process as scientifically as you can.
Rekha: It's the cubes being put in a glass...after a few minutes it starts melting.
I: I see.
Rekha: And then after 10 minutes it has been completely melted...and it has gone to water.
I: Now could you explain to me as scientifically as you can how melting takes place?
Rekha: They are cubes so when they were exposed to heat, like it was put in open place so it gained energy then it melted. **A.1.1; A.1.5**
I: How does that gain in energy actually cause the melting?
Rekha: From the atmosphere.
I: But how does it actually cause melting?
Rekha: Oh you want like the solid particles and the water...the liquid particles.
I: Yeah.
Rekha: Like the ice it's solid and when energy was applied it melted...and turned into liquid particles...it vibrated and that's what I know. **A.1.2**
I: Could you say any more about it?
Rekha: The liquid particles are not that close and they take the shape of the container. **A.1.3**
I: So why does that change take place?
Rekha: You mean the solid to liquid?
I: Yes.
Rekha: That's what I'm saying it has been melted.
I: But why?
Rekha: They gained energy. **A.1.5**
I: Could you say anything more about the melting process?
Rekha: No.
I: OK...and this substance on the outside of the glass is what?
Rekha: It's the condensation part.
I: Where does that come from?
Rekha: From the atmosphere around it. **A.1.4**
I: How does that come...what's the process...the process of condensation, how is that caused?
Rekha: Like when it melts, as it gets attracted to cold surface and the atmosphere around it they interact like eh...the cold surface is there and the atmosphere present around makes the droplets form on the outside of the glass.
I: Why?...How does the cold surface cause that to happen?
Rekha: I'm not sure.
Later we returned to this card after Rekha had explained the condensation of water vapour in the context of a boiling kettle? (Card 3)
I: So how do you think it might have been formed?
Rekha:...Are the two related? (The condensation in cards 1 and 3)
I: What do you think?
Rekha: Yes.
I: So what do you think happens?

Rekha: It meets the cold surface and changes back to water, the condensation process.
I: And during that process what happens?
Rekha: It loses energy. **A.1.5**
I: When you say it loses energy what specifically loses energy?
Rekha: The water vapour.
I: I see.

In this episode Rekha's explanations appear to be consistent with the apparent improvement in understanding revealed by the post-test. Here she not only states that heat is required for melting **(A.1.1)**, but also links this to a gain in energy **(A.1.5)**. Furthermore, although some probing was required to elicit reference to particles, Rekha demonstrates that she has constructed a partial molecular model since the initial interview. This model is used to link energy input to increasing particle vibration **(A.1.2)** and spatial distribution **(A.1.3)**.

While initially unable to explain condensation, Rekha later asked to return to Card 1 and provided an explanation at the macro-level. The improvement Rekha demonstrated on the post-test items relating to Card 1 appeared to be supported later by her qualitative responses to this card. Whereas prior to instruction her responses were extremely limited with no reference to particles or energy gains and losses, post-instruction these concepts were being incorporated. Furthermore, these concepts were also included in her explanation of evaporation (Card 2). Prior to instruction Rekha could only provide a macro-level explanation of this concept.

Rekha: Like when we boil something the heat is there and the water evaporates in the form of vapour...it goes up. In the atmosphere it mixes up with the atmosphere. **A.1.1**
I: And how exactly does the heat make it do that?
Rekha: Em...like the sun's rays gets in contact with the water then it makes it warm...like the heat...as it is heated it is evaporated in the form of vapour. **A.1.1**
I: Could you say more about that?
Rekha: No I don't think so (laughs).

However, post-instruction, despite an initial tendency to restrict her response to the macro-level, she was able to provide a much more scientific explanation of evaporation which incorporated the underlying molecular mechanism.

I: What has happened to the puddles?
Rekha: They have evaporated...they gained energy. **A.1.5**
I: Where did that energy come from?

Rekha: From the sun.
I: So how does that gain in energy actually cause the puddles to evaporate?
Rekha: Like they gain energy and they move faster. **A.1.2; A.1.1**
I: When you say they...
Rekha: The water...
I: The water what?
Rekha: Like you said the water is here in the rain puddles and as they gained energy it evaporated.
I: You said they gain energy and they move faster but I just wondered what you meant by they...the whole puddle?
Rekha: No the water particles. **A.1.2**

Overall, this suggests that the experimental treatment had been successful in facilitating the construction of some key concepts related to state change with this student. Furthermore, the explanations Rekha provided in this section of the post interview, in which concepts such as energy gain and particle movement were linked appropriately, indicated conceptual understanding rather than rote learning. Certainly they related to each other in a substantive, non-arbitrary way suggesting conceptual understanding as defined in chapter 1 of this thesis.

However, in the domain of pressure Rekha's conceptual development was less marked. Her initial response to the model lung activity indicated that she was unaware that it related to pressure.

I: What will happen to the balloon when I pull this (diaphragm) down?
Rekha: I'm not sure.
I: Do you know why that happens?
Rekha: Let's see...you pull this one and the air gets into it?
I: Yeah.
Rekha: The air from this tube gets into the balloon...but I don't know the purpose of this one...I don't know what's happening there.
I: You're not sure what's happening?
Rekha: This is pulled out...maybe the air goes out.
I: Out where?
Rekha: Out of the jar (bottle)...
I: But how will the air go out of the bottle if the plastic's there and it's completely sealed?
Rekha: I'm not sure.
I: Do you know what aspect of science this relates to?
Rekha: I'm not sure.

In this instance Rekha's understanding was so limited that she could provide no real conceptions either scientific or alternate. Her post-instruction response revealed that her understanding of gas pressure had developed to some extent but still appeared to be quite confused and messy.

I: What will happen to the balloon when you pull this down?
Rekha: It will expand.
I: Could you explain why that happened...first of all what is it to do with?
Rekha: Like when the diaphragm it gains energy from the atmosphere...that's why it inflates.
I: What gains energy?
Rekha: The balloon. **New alternative conception**
I: What aspect of science or matter are we dealing with here?
Rekha: ...it's the pressure.
I: Yeah...so how does the pressure work with this whole thing?
Rekha:...like when the diaphragm is pulled down the pressure inside increases. **C.2.8**
I: Increases and how does that make the balloon inflate?
Rekha: I don't know.
I: Can you remember what actually causes air pressure or gas pressure?
Rekha: What do you actually mean by that?
I: What is it about the gas which causes pressure?
Rekha: Like when energy is applied the pressure increases. **New scientific conception**
I: Yes that's true but why does that happen?
Rekha: The particles...the gas particles move faster?
I: Yeah in moving faster what do they do to cause the actual pressure?
Rekha: I'm not sure.

In this case Rekha was able to link the activity to the air pressure. However, she appeared determined to 'chain' the particle/energy construct to the activity and consequently revealed that she had developed no real conceptual understanding of pressure change in this context. It seemed there were two key deficiencies in her understanding. Firstly, she had failed to construct a coherent molecular model of pressure which incorporated particle collisions. This in turn appeared to prevent Rekha understanding that increasing the volume of a fixed mass of gas reduces its pressure. Such a construct requires reference to particle collisions.

Rekha may well have found pressure more conceptually difficult than state change. Certainly the lack of appropriate conceptual links, even after instruction, indicated that her understanding was limited. This was reflected in her performance on the four items relating to this activity. On the pre-test she produced one correct response. This had risen to two on the post-test as, along with her original correct response, she had become aware that the activity related to air pressure rather than gravity.

Finally, Rekha's view of conservation during evaporation changed after the treatment. In the initial interview she asserted that liquid acetone would be heavier than the same quantity of gaseous acetone because gas has no weight. This view was reaffirmed during the pre-test where she repeated this statement almost verbatim in her justification of item 29. However, by the end of the treatment this view had changed as her post-test response stated that the weight did not change. This was confirmed by the post-treatment interview response to Card 8.

> Rekha: It (the gas phase) should weigh the same because the same substance is there. Only thing is that it's in liquid form in the first one and after being heated it has just mixed with air.

This response implies conceptual change from the view that mass is lost during a physical change **(B.2.1)**, to the notion that there is no loss of matter associated with this transformation. However, despite this apparent conceptual change, Rekha interpreted the statement in item 45, 'Air has weight' as an alternative conception, and later in the post-intervention interview claimed that she was not sure if air had weight. She seemed to be unaware or unconcerned by these inconsistencies, a reaction similar to that reported for children in Western research. Furthermore, it indicated that the apparent conceptual change in Rekha's views was clearly incomplete in this instance.

Nevertheless, it appeared that Rekha had constructed an improved understanding of some aspects of matter based on the quantitative and qualitative data available. The improvement in conceptual understanding was not consistent across all the conceptual areas covered but this would have been unlikely given that some areas such as pressure seemed to be more conceptually difficult than others for the students.

Later, in a delayed post-test comprising eleven items, Rekha's performance indicated that her apparent improvement in understanding matter had been largely sustained. While Rekha scored only 18% on the same eleven items in the pre-test, this rose to 100% on the post-test. The delayed post-test administered ten weeks later showed a drop to 72%, but this still represented a considerable improvement on her original effort and indicated that much of her knowledge gain was being sustained. The delayed post-test data will be discussed in more detail in the final section of this chapter.

7.7.1.3 Mereani (Fijian female)

Like Rekha, Mereani also opted out of science at Form 4 and claimed she did not enjoy it at school. However, she worked with considerable enthusiasm throughout the experimental treatment. Unfortunately, there were no initial interview data for Mereani. Nevertheless it was still possible to evaluate her pre-test/post-test improvement of 40% (the largest for the group), in terms of her post-instruction qualitative explanation.

Mereani initially scored two out of a possible six on those items relating to Cards 1 and 2. Her qualitative justifications, amongst other things, revealed that she equated evaporation with absorption, viewed humidity as responsible for melting ice cubes and was unsure whether ice cubes released heat energy upon melting. However, she responded to all six items correctly in the post-test with highly satisfactory justifications in every case. When interviewed later using the same cards her responses were as follows.

Post-instruction response to Card 1
Mereani: Right so that's ice melting....that's solid ice.
I: Yes.
Mereani: OK ice melts because they have gained energy...and here like the particles here (pointing to ice cube) they are held closely but still the particles are vibrating...when they gain energy they tend to move more rapidly...faster, that causes...I mean they move faster maybe sliding over each other that causes the melting of ice since they have gained energy. **A.1.2; A.1.4; A.1.5**
I: I see and what's this on the outside of the glass.
Mereani: These are water droplets like eh...do I need to explain this too?
I: Yeah.
Mereani: (laughs) Like eh water particles in the atmosphere not very far but just around...near to that glass of eh ice cubes...of eh I would say that's melted ice. **A.1.4**
I: Yeah this is after 10 minutes you see it's the same glass after 10 minutes.
Mereani: So the water particles in the atmosphere around that eh glass are attracted to that cold surface so when they hit the cold surface they lose energy and there is a very weak bond between the particles so that's why the water droplets are formed...the water particles are not from very far off...and they are not chosen like...it's randomly...the ones that hit they lose energy and they are bonded together with a weak bond with other particles that's why this water droplets form. **A.1.5**

Card 2
I: This one...the puddles where have they gone?
Mereani: Oh water particles have gained energy since...the heat energy is supplied by the sun, so water particles they have gained energy...they have become...not lighter they have moved faster and they have gained enough

energy so that they can go off into the atmosphere so they are now in the atmosphere as water vapour...what would I say, water vapour? **A.1.5**
I: Yes...does heat absorb the water particles?
Mereani: No heat does not absorb water particles but it is the water particles that gain heat energy. **A.1.5**

Although not one of Mereani's pre-test justifications had mentioned particles, she had apparently constructed a coherent molecular model by the end of the treatment. She was able to link concepts effectively in all of her explanations of state change e.g., **(A.1.2; A.1.4 & A.1.5)** and she incorporated the concepts of adhesion and cohesion into her description of condensation, although she did not actually use these terms. Once again Mereani's explanations of state change, with their appropriate conceptual connections appeared to indicate conceptual understanding rather than rote learning, and confirmed her quantitative improvement on the post-test.

Mereani's understanding of the concept of pressure also showed a marked improvement on the basis of her test performance. An initial score of zero on the four items relating to the Model Lung rose to four on the post-test.

Model Lung
I: Can you explain why the balloon inflates when you pull this (diaphragm) down?
Mereani: When I pull down the balloon the air pressure inside is less than the air pressure outside because I have increased the volume so air pressure outside is greater therefore air is being forced inside...pushed inside the tubing and that causes the balloon to inflate. **C.1.4**
I: What causes the pressure to decrease when you increase the volume.
Mereani: The pressure is decreased if we increase the volume but what can I say the particles of air are still the same but you only change the volume...like here the particles of air inside here they're still the same and when I increase the volume like there is more space for the air particles to distribute themselves.
I: And what actually causes pressure?
Mereani: What causes pressure...would it be gas?
I: It is the gas but...
Mereani: It would be the gas particles pressing on to the outside.
I: Could you put that another way?
Mereani: Pushing? **C.1.3**
I: Well perhaps colliding.
Mereani: Yeah colliding with the sides of the container.

Mereani was now able to link a number of concepts to produce an effective explanation of the observed phenomenon. She introduced the concept of differential pressure by linking the increased volume which resulted from pulling on the diaphragm to reduced pressure within the bottle **(C.1.4)**. Using this construct she was able to avoid the alternative view that air was sucked into the balloon and instead stated that the air was forced inside. Furthermore, Mereani could explain why increasing volume caused pressure reduction using particle theory **(C.1.3)**.

This was the most effective explanation of gas pressure provided by any of the students, and in fact all Mereani's explanations were in keeping with the scientific view, indicating that, for her, significant learning about matter had taken place. This was further confirmed by her performance on the eleven item post-test administered ten weeks after the treatment. Initially, she scored only 18% on these eleven items, but this had risen to 100% by the post-test and remained at 100% for the delayed post-test. The fact that this improvement was sustained even after ten weeks points to conceptual understanding rather than rote learning.

Certainly she was one of the most enthusiastic and determined members of the experimental group. As mentioned previously, as the treatment proceeded her status changed from an 'apprentice' drawing on the ideas of her fellow students to construct understanding, to the role of 'tutor', in which she proceeded to share her knowledge with less confident peers to help in their knowledge construction.

7.7.1.4 Milika and Laisani (Fijian females)

Both of these subjects had dropped science at the first opportunity, Milika because she did not enjoy the subject and Laisani because she felt it was inappropriate to pursue senior science having achieved only an average grade at Form 4. Initial interviews with both subjects revealed their content knowledge in the domain of matter to be extremely weak. To illustrate this a short segment from each subject's pre-treatment interview is provided below.

Laisani - Card 8 - Acetone
I: What do you think has happened here?
Laisani: Like this acetone have turned into water and that's why the seal has gone up. **B.2.3**
I: No the seal...it shouldn't have gone up the seal just stops anything getting out. So it's turned into water if you heat it?
Laisani: Yeah.
I: If you were to take the weight of this and the weight of this would there be a difference or would they be the same.

Laisani: It would be different.
I: Which one would be heavier?
Laisani: This one (liquid acetone).
I: Why?
Laisani: With the water inside it, when it turns into water. **B.2.1**
I: So when it turns into water it will be heavier.
Laisani: No, I think the other one would be heavier.
I: Why?
Laisani: Because this acetone haven't been turned into something that's why it's acetone itself when it is put here so it will be heavier. When it is heated it will be changed into something and the weight that is put inside here as it is acetone itself it will be heavier than when it is heated and changed into something else. **B.2.3**
I: Do you think it would be possible...sorry...what do you think would happen if I was to take this tube and cool it down?
Laisani: I'm not sure what would happen.

This episode revealed that Laisani's view of state change and matter conservation appeared to be extremely confused, and was fairly typical of her responses in general. Her poor conceptual understanding was confirmed by her pre-test performance in which she registered a score of 24% (12 out of 50 scientific responses) with 42% of her responses indicating the alternative view and 34% being unsure. The situation was similar for Milika.

Milika - Card 3 - Boiling kettle
I: In here...in the boiling kettle you can see some bubbles, what do you think the bubbles are made of?
Milika: Heat caused by...the heat inside.
I: How does the heat cause the bubbles to form?
Milika: The water is rising.
I: So the heat causes the water to rise, so do you think inside these bubbles...
Milika: There's air. **B.2.5**
I: So where does the air come from.
Milika: The water just turns into air. **B.2.3**

Once again this apparently weak content knowledge was confirmed by the pre-test performance where Milika scored only 22%.

The post-test scores produced by both subjects revealed a substantial improvement in performance with Laisani recording 58%, a gain of 34% and Milika 60%, a gain of 38%. This gain appeared to represent a considerable improvement in understanding, particularly as the correct selection of a true/false response was not considered suitable unless accompanied by an appropriate qualitative justification.

However, this improvement was not always apparent from their responses during the post-treatment interviews, as the following responses by Milika show.

Pre - treatment response to Card 1 - Melting ice-cubes
I: Can you explain what's happening to the ice in the picture and why it has happened?
Milika: I think it's melting.
I: Why is it melting?
Milika: Because of the heat. **A.1.1**
I: And do you know how the heat actually makes ice melt...do you know the scientific explanation.
Milika: No.
I: You're not sure of that?
Milika: No.
I: You can see it's melted down into water, but there are also water droplets forming on the outside of the glass. Do you know where that comes from?
Milika: From the heat outside? The air?
I: I won't tell you if you are right or wrong, you just tell me what you think.
Milika: OK. From the atmosphere...gives out that. **A.1.4**
I: And do you know why that happens?
Milika: Why they have droplets?
I: Yes.
Milika: I think it's because of the cold air...cold air...a mixture of cold air and hot air.

Post - treatment response to Card 1 - Melting ice
I: Could you tell me what this process is and explain it to me as best as possible what would you say?
Milika: It's melting.
I: And what does melting mean?
Milika: It was cold and it's now hot...warm. **A.1.1**
I: How does melting...as scientifically as you can, how would you explain melting?
Milika: ...I don't know.
I: Not sure?
Milika: No.
I: OK what's on the outside of the glass?
Milika: Water droplets.
I: Where do you think they've come from?
Milika: ...from the particles outside? **A.1.4**
I: Do you know what has caused them to form on the outside.
Milika: The temperature in this (pointing to glass) is different from the temperature outside.
I: Yeah...so how does that affect them?
Milika: When they would interact they would form water droplets.
I: What is it about that interaction which causes them to form water droplets.
Milika: I don't know.
Later the subject asked to revisit Card 1 after mentioning particles in relation to Card 3.
I: What about the ice one, could you explain that in terms of particles, how the ice melts?

Milika: Particles in ice are held together and when they change into water they move about but are held together.
I: What makes them move about?
Milika: Vibration?
I: What is it that causes the vibration and the moving about.
Milika: I don't know.
I: Could you explain that in terms of particles (condensation)?
Milika: ...Particles from outside they are freely...they move freely and em once they hit the cold surface they're held together and they form water droplets...
I: Why do they suddenly...
Milika: Because they hit a cold surface...once they hit a cold surface they would be held together.

Comparison of these pre- and post-treatment responses indicated that little conceptual development had occurred. It appeared that, between the first and second interviews, the subject had not developed a coherent molecular model of matter. As a result, coding both responses from the CPI showed no difference. Nevertheless, the subject had incorporated the concept of particles into a later response although she could not link this concept to that of energy. Laisani's responses often indicated a similar lack of conceptual development.

Pre - treatment - Card 1 - Melting ice
I: Could you explain to me as scientifically as you can what is happening in this picture?
Laisani: Condensation.
I: Well what's...these are ice cubes...what's happening to the ice cubes first of all.
Laisani: They melt.
I: Why do you think they melt?
Laisani: Because they are inside a glass and that glass is warm. **A.1.1**
I: I see.
I: What actually does the heat do to make them melt?
Laisani: ...
I: Not quite sure?
Laisani: Yes.
I: That's OK...and what would you say this was on the outside of the glass?
Laisani: This ice cubes they turn to water inside this glass, since they are cold the...that's why the water forms outside the glass.
I: And when the water forms outside the glass, do you know where that water comes from?
Laisani: From the heat that turns the cubes into water. **A.2.7**
I: Do you know why that water comes to form on the outside?
Laisani: ...
I: Can remember any of the science behind it?
Laisani: The science what?

I: Can you remember any of the things from science which would help you explain why when you take a cold glass from the fridge you get water on the outside.
Laisani: No.

Post - treatment - Card 1 - Melting ice
I: Could you explain as scientifically as you can how this process takes place?
Laisani: Like we put ice cubes in one container and what we see is that water vapour or water is seen outside and these ice cube is started to melt.
I: The process of melting could you explain how that takes place?
Laisani: Like it is put outside and the heat that is given by...the energy from the atmosphere helps this to melt. **A.1.1**
I: How does that actually happen?
Laisani: Like it touches the sides of this container.
I: Could you say anything more about the actual process of melting?
Laisani: ...like before it is taken out like it is in a cold place and that's why it is like this but when you take out like it's in a hot atmosphere so it starts to melt. **A.1.1**
I: And the scientific explanation of melting can you remember that?
Laisani: ...something on pressure...no it's the energy from the atmosphere that help these ice cubes to melt. **A.1.5**
I: What does the energy actually do?
Laisani: Like it touches the sides...no...
I: Not sure?
Laisani: (laughs)
I: Well there are some drops of water on the outside of this glass, where has that come from?
Laisani: From the atmosphere...because it is made up of many particles of water. **A.1.4**
I: And how does this process take place.
Laisani: The energy...the heat...the energy...it is hot and when it touches the cold eh it's cold inside so we can see water vapour outside.
I: OK what causes that water vapour to form on the outside?
Laisani: Because of the heat that's from the atmosphere...it touches the cold surface...

Laisani also failed to apply a coherent particle model to most of her explanations. However, there was evidence that she was attempting to incorporate the concept of energy into her explanation but, like Milika, she failed to link this to the concept of particles. In a later post-treatment example, however, she almost succeeded in making this connection.

Card 3 - Boiling kettle
Laisani: It's the energy from...the energy...the energy helps this or allows this water to boil.
I: How does it do that?
Laisani: Like from the bottom heat it is heated and so this particles, when they move up they...

Here Laisani appeared to possess the component concepts necessary to construct a molecular model but failed to link these to provide a coherent explanation. However, Laisani was more confident about explaining the concept of conservation, after treatment.

Post - treatment - Card 8 - Acetone
I: Can you explain to me what you think has happened here?
Laisani: OK all the acetone over here like they will be on the glass on the sides of the glass due to evaporation.
I: So if it evaporates what does that mean.
Laisani: Like it has been heated up by the heat that is given out from here and that helps with the evaporation. **A.1.1**
I: Sorry.
Laisani: The energy given out by the heat...has eh changed these particles of acetone into gas it helps in evaporation. **A.1.5**
I: So they've evaporated into...
Laisani: Water vapour...no...acetone vapour. **B.1.1**
I: So if I took it and cooled it again what would happen?
Laisani: We'll see droplets of acetone again here (pointing to the bottom of the tube).
I: If I was to take the weight of this one and then the weight of this one what would I find?
Laisani: The same, because none of those particles have gone out. **B.1.2**
I: How exactly does the heat make the acetone evaporate?
Laisani: The energy given by the heat has helped.
I: What has that done exactly...has helped what?
Laisani: Helped in evaporation.
I: Yes but what is it about the heat, the heat...
Laisani: Gives out energy. **A.1.5**
I: Yes it gives energy but to what?
Laisani:...to help the particles move apart...**A.1.3**
I: As well as moving apart does anything else happen to them.
Laisani: To the particles?
I: Yes.
Laisani: They move faster. **A.1.2**
I: I see.
I: And when you cool them what happens to their energy?
Laisani: They move together...they come close together. **A.1.3**
I: I see.

This explanation revealed a major improvement on her pre-treatment response which contained no scientific conception and a complete lack of cohesion. In this instance, however, Laisani applied the concept of particles effectively to explain conservation (**B.1.2**). Moreover, in this context she was able to link the concept of particles and energy into a model to explain evaporation (**A.1.2; A.1.3**). It is only possible to speculate why she could articulate a particle model in this context but not in that of melting or condensation. It seemed the conceptual area of matter conservation may have evoked a representation of particles more readily than that of change of state. This in turn may have engendered more confidence in Laisani making it easier to link energy and particles and thus explain evaporation. Although at one point Laisani almost reverted to an alternative view of state change which involved non-conservation of matter, she was quick to correct this to the scientific view. In fact this episode contained no evidence of alternate conceptions.

These two subjects, despite making large gains on the post-test, did not always provide interview explanations which were consistent with an overall improvement in understanding of the topic of *Matter and how it changes*. This may have been due, in part, to rote learning of some concepts during the treatment. Furthermore, the post-test provided the subjects with a statement from which to work, whereas they had to construct and articulate their own responses in the context of the interview.

However, there were certain examples of complete consistency between the qualitative and quantitative findings. For example, Milika clung tenaciously to the alternative view that water changed into air when boiled and thus the bubbles in boiling water were formed from air. This view was expressed consistently across pre- and post-interviews and the pre-, post- and delayed post-test. Laisani on the other hand changed her conception of mass conservation during the experimental treatment and maintained the scientific view across the post-treatment interview and test and the delayed post-test.

Overall, there was a strong similarity between the performances of Milika and Laisani across the three tests, with both starting from a very low level, 0 and 9% respectively. Immediately after the treatment they registered large gains on the post-test with both scoring 73%. However, this dropped to 45% for both on the delayed post-test. The fact that their initial gains were not sustained in the delayed post-test was probably indicative of their often tentative responses in the post-treatment interviews where, although they exhibited some new conceptual connections, these were rare and rather inconsistently applied. Certainly, there was little evidence that they were making sufficient new conceptual connections to have achieved a robust understanding, and their delayed post-test performances tended to confirm this.

7.7.1.5 Sheetal (Indian female) and Seremaia (Fijian male)

So far the case reports have featured the progress of students from the experimental group who had completed high school with the minimum science requirement and in general did not favour this discipline. The final two case reports focus on students who pursued science to the end of their high school career and stated that they would have gone on to do university science had their grades permitted.

Both Sheetal and Seremaia achieved higher than average performances on the pre-test with scores of 62% and 54% respectively. These results probably reflected their stronger backgrounds in science. However, both students exhibited alternative conceptions and incomplete understanding of some aspects of science. For example, the pre-treatment interview data provided by Sheetal revealed her conceptual understanding of pressure to be weak.

Pre-treatment explanation of the Model Lung
I: What will happen to the balloon when I pull down on this diaphragm?
Sheetal: The balloon will get filled up, if the diaphragm moves down then...
I: OK let's see.
I: Why does that happen?
Sheetal: That has to do something with the breathe in, breathe out?
I: It's a similar process, but why when I pull down on the diaphragm does the balloon expand?
Sheetal: If the diaphragm is pulled down then air comes into the balloon, in other words the balloon is the double of the lungs.
I: Yeah, but why does it happen?
Sheetal: Because we have to breathe in.
I: Yes we have to but this doesn't have to. What I'm asking you is can you explain why that happens in the model?
Sheetal: Because when the diaphragm is pulled down the gas particles the air which is taken in, a lot of particles are taken in so when the diaphragm is pulled down then the particles go down and a few particles go in the balloon. Which means in our case lungs, so if it's the air is taken in, the diaphragm goes down due to the particles and also the lungs.
I: Could you say why that happens?
Sheetal: No I don't think so.

Here Sheetal linked the model to the process of breathing but simply reported her observations rather than the underlying principles. She failed to associate verbally the activity with the concept of pressure and she believed that the diaphragm flattened because the balloon expanded rather than the reverse. This confused construct of the observed phenomenon was later confirmed in the pre-test with a score of one out of a possible four on items relating to this activity.

Even in aspects of matter such as change of state which might be considered conceptually less difficult than pressure, Sheetal's explanation contained few scientific conceptions.

> **Pre-treatment response to Card 1-Melting ice**
> I: During melting what actually happens? Can you explain it as scientifically as possible?
> Sheetal: The ice cubes here they are very cold and they are of a very low temperature so when they are placed in the environment, the environment temperature is about 26 or something like that, so when it goes in contact with the environment so it starts to melt in order to get to the temperature level of the environment, so in the process of melting it absorbs the heat form the environment. **A.1.1**
> I: Could you say anymore about that?
> Sheetal: Not really.
> I: And you see the final glass here after 10 minutes, what's on the outside of the glass?
> Sheetal: Water droplets.
> I: Where has that water come from?
> Sheetal: That water comes from the surrounding, because since the surface of the beaker is very cold water droplets in the surrounding, they get to the sides of the glass. **A.1.4**
> I: Why does that happen?
> Sheetal: They find it very suitable so they come in contact and they always form water droplets.
> I: Why do you say suitable?
> Sheetal: Because as it is the environmental temperature is high so the water vapour is in the surroundings everywhere, so if they find a very cold place they find it very suitable.
> I: Can you explain that process further?
> Sheetal: No I'm not sure about that.

Despite being asked to explain the changes as scientifically as possible, Sheetal failed to apply a particle model during her response. Her final utterances also implied a highly anthropomorphic view of matter which was confirmed by her response to item 49 on the pre-test in which she asserted that the particles of matter were living.

Sheetal's explanation of evaporation did incorporate a particle model, but this explained particle behaviour only in terms of changing spatial distribution **(A.1.3)** and omitted the energy relationships.

Pre-treatment response to Card 2 - Evaporating puddles.
I: Where do you think the puddles have gone in the afternoon?
Sheetal: When it rains the water fills up the puddles, but in the afternoon when the sun is bright all the water in the puddles they evaporate due to the sun's heat, strong rays of the sun they evaporate. **A.1.1**
I: How would you explain what happens when water evaporates?
S; Evaporate is the changing of water from liquid to gas.
I: Why does that happen? Or how does it happen?
Sheetal: The liquid particles when they are in the state of liquid they are colliding each other they are very far apart but when they get the sun's heat rays then they try to get further apart and form gas so they become very far apart. **A.1.3**

Seremaia was not interviewed prior to the experimental intervention but his pre-test data also revealed a number of key alternative conceptions similar to those displayed by Sheetal, such as the view that particles were living and that gravity was involved in pulling air into the balloon of the model lung. However, one response did indicate a well conceptualised particle model, as in his response to item 50 which stated that heating of a substance causes the particles to become charged and repel one another. While this item appeared to generate an alternative conception amongst many students with more tentative knowledge, Seremaia asserted that the statement was false because heating caused the particles to gain energy and vibrate faster. This response suggested a robust understanding in the face of a persuasive alternative conception.

Both students made gains on the post-test with Sheetal scoring 76% and Seremaia 86% and the students' ability to explain various phenomena appeared to be consistent with their post-test performance.

Post-treatment response to Card 1-Melting ice
I: Could you explain to me using as much science as you can what's happening here.
Seremaia: When the ice cube is put inside the glass...the temperature of the glass is quite high than the cubes. So when they are in contact some of the energy from the temperature of the glass is transferred into the cubes so it decreases the energy into the cubes so the bonds break like that and they melt. **A.2.12**
I: So when you say the bonds break...
Seremaia: Actually there is increasing movement...**A.1.2**

I: Of what?
Seremaia: Of the cube...of the particles in the cube so that's why they break up and then dissolve into liquid.
I: And this substance on the outside of the glass after 10 minutes...what is that?
Seremaia: That is water vapour from the air...when it bump into the glass it immediately condense particle by particle onto the...that is due to the em energy from the...energy loss from the water vapour as it touched the glass. **A.1.4; A.1.5**
I: Why does it lose energy?
Seremaia: Because of the temperature of the glass it decrease the energy...it reduces the movement of the particles of the water vapour so it sticks one by one to the glass when they form up they form water droplets.
I: So they lose energy?
Seremaia: Yeah.

Post-treatment response to Card 2-Evaporating puddles
I: What has happened to the puddles here?
Seremaia: The...puddles were in the morning and in the afternoon when the sun was shining the puddles gained energy...the particles inside the puddles...they gain energy so they move faster and more rapidly...so when they are all moving rapidly they break up the bonds and it change into water vapour. **A.1.5**
I: Where do they get their energy from?
Seremaia: They get it from the sun.
I: Is that heat energy or heat and light.
Seremaia: Heat energy. **A.1.1**

Post-treatment response to Card 4-Dissolving sugar
I: What has happened to the sugar in this case?
Seremaia: It has mixed with the water. **E.1.3**
I: That process of mixing do you know what it's called?
Seremaia: Em does it dissolve?
I: Why do some substances like sugar dissolve and other substances like sand...sand grains not dissolve?
Seremaia: First of all there has to be attraction, water particles and the sugar...if they are attracted then they can dissolve more easily...because sand is not really attracted. **New scientific conception**
I: Where do the sugar particles go?
Seremaia: I mean they fill up the gaps between the water particles. **E.1.3**
I: And you see a few crystals left at the bottom. Why has that happened?
Seremaia: All the gaps between the water particles have been filled up by sugar and the solution is said to be saturated. **E.1.2**
I: And could you get the sugar back from the solution?
Seremaia: Yeah certainly.
I: How would you do that?
Seremaia: You would heat it but you have to control it. **E.1.1**

Despite some confusion over energy transfer into the ice cubes, and initial scientific terminology, Seremaia provided explanations which were generally in keeping with the scientific view. In each instance he incorporated a particle model into his response and went further in attempting to include the concepts of adhesion and cohesion.

Sheetal's responses to change of state revealed a qualitative improvement when compared to those from the initial interview.

Post-treatment response to Card 1-Melting ice
I: Can you explain as scientifically as possible what is happening in this picture.
Sheetal: The ice cubes...when it is put in the glass it starts to melt so the particles...water vapour particles in the atmosphere when they find a cool surface they lose energy and they condense on the outside of the glass in the form of water droplets...the particles of water vapour in the atmosphere they lose energy and they...**A.1.5**
I: What causes them to lose energy?
Sheetal: The cold surface.
I: Could you explain the process of melting to me again?
Sheetal: Em the process of melting is were solid goes to liquid state but ice can be reversible it can again...water can again go to solid.
I: OK that's what it is, but why does it happen?
Sheetal: Liquids can take the shape of the container so they have got slight spaces in between them which can glide over each other, the particles of the liquid, so if we freeze them so it eh the particles contract and they turn to ice, the particles in there, in the ice are compactly packed and they only vibrate.
I: How does it change from ice to water...I was more interested in the melting process?
Sheetal: Oh melting process...ice eh the particles in the ice have absorbed the heat energy and when they are melting they release heat energy...they release energy and...**A.1.5; A.2.12**
I: A moment a go you said the particles in the ice absorb heat...is that when they freeze?
Sheetal: During freezing.
I: They absorb heat energy?
Sheetal: So when in the melting process they release heat energy. **A.2.12**
I: So what happens to the particles?
Sheetal: They change to liquid state...the particles...the ice particles eh are still the same particles not the different particles...in other words water particles...it's the same particles.
I: So why is it they can move in one state and not the other?
Sheetal:...not sure.
I: I see.
Break for lunch
Sheetal: Sir I wanted to explain the ice one again.
I: That's OK, go ahead.
Sheetal: When the ice cubes start to melt they gain energy from the atmosphere...they gain energy...so when they gain energy the particles of the ice they vibrate, they move apart and they start to melt...so the particles they start to melt as a result of gaining energy when they are freezing the particles of the water they lose energy and then they freeze to ice. **A.1.1; A.1.2**

I: Did you look that up from your notes at lunch time (laughing).
Sheetal: No Sir I just thought about it more.
I: Yes early you had it the opposite way round...the gaining and losing energy bit...you said ice releases energy when it melts...
Sheetal: Sometimes we...
I: Yes it's easy to get these things confused when it's not your first language.

Post-treatment response to Card 2-Evaporating puddles
I: Can you explain what has happened in this picture?
Sheetal: The water in the puddles they evaporate...turn from liquid to gas state and they evaporate the process is called evaporation...and they remain in the atmosphere as water particles in the form of water vapour.
I: How does evaporation take place?
Sheetal: Evaporation takes place when eh the heat from the sun eh the water particles in the rain puddles they...when the heat comes they gain energy...they gain energy and they move apart so it evaporates. **A.1.2**

Initially, Sheetal attempted to explain melting and condensation in terms of energy change. While she successfully explained condensation, her explanation of melting was extremely tentative and confused and at one point she contradicted herself within the same utterance. However, it appeared while reflecting on this during the enforced lunch break she was able to construct the scientific view. This reflection may also have helped in her construction of evaporation. This instance provided some evidence that this student was using elements of metacognition in her construction of knowledge.

Finally, on the four items which related to the model lung, Seremaia had improved his performance from two to four correct responses, while Sheetal had dropped from one to zero. Once again there was evidence from the post-interview data to support the view that Seremaia's understanding of this conceptual area had improved.

Post-treatment explanation of the Model Lung
I: When you pull this down what will happen to the balloon?
Seremaia: It will inflate.
I: Can you explain why that happens?
Seremaia: Yeah pressure is affected by volume...so while pulling this thing out it increases the volume, and when you increase the volume there's a vacuum inside so the air is pushed in. **C.1.4**
I: So you said there was a vacuum inside so what actually happens to the pressure inside?
Seremaia: When I pull it down the volume increases so the pressure decreases...the pressure outside is more than the pressure inside so the air is pushed in.
I: What actually causes air pressure at a particle level?

Seremaia: I think the movement of the particles...the amount they hit the sides of the container. **C.1.3**
I: So if you heat a gas what happens to the pressure.
Seremaia: It will increase because there is a rapid hitting of the particles to the side of the container, so it will increase the pressure.
I: You...there was one thing I forget to ask you...I mean did you find that you understood all this before or...
Seremaia: To be honest I think I understand it more now...nearly 75% more and with more logic too.

This response not only indicated that Seremaia could use the particle level concept of collision to explain pressure at the macro-level, but he could link concepts such as volume and temperature to particle behaviour in order to construct an explanation of pressure change. However, Sheetal's response to the same activity indicated no improvement in her understanding.

Post-treatment explanation of the Model Lung
I: What will happen when I pull this down?
Sheetal: When we pull the diaphragm down the air is sucked in and the pressure...when the air is sucked in...when the diaphragm is pulled down air is sucked in and eh the space...eh the volume increases and eh...that's all. **C.2.4**
I: The volume increases...now you said is sucked in why is that?
Sheetal: Because the volume inside is increased...the volume is increased so it can accommodate more particles...air particles.
I: Is there anything happening to the pressure inside?
Sheetal: Pressure...increases...**C.2.8**
I: Why is that?
Sheetal: I hope I'm right or is it the opposite?
I: Well what do you think?
Sheetal: No but I know that when air is sucked the volume is increased...pressure decreases...**C.1.4**
I: Why does that happen?
Sheetal: Is it the force?
I: What sort of force?
Sheetal: Like the pulling of the diaphragm? **C.2.4**

Although she mentioned particles, Sheetal never linked the concept of their collisions to pressure. Consequently she was unable to construct a particle-level explanation of why volume increase reduced pressure. She appeared to have little confidence in her explanation and ultimately linked the influx of air to the balloon to the 'pulling force of the diaphragm.' This response suggested that, while Sheetal had included some new concepts when compared to her initial response, for example, the relationship between volume and pressure and the notion of particles, these appeared to have been learnt by rote as they were either unconnected or incorrectly connected.

This may explain why Sheetal was unable to improve her performance on the post-test items which related to this activity.

This qualitative check of experimental students' post-treatment understanding tended to support the findings of the post-test. Certainly, it was often possible to confirm subjects' improved performance on a specific set of post-test items by examining their post-interview responses for evidence of substantive, non-arbitrary conceptual connections within the same topic. In general the qualitative check tended to support the outcomes from quantitative data and, as such, acted as confirmatory evidence for the superior learning outcomes for students in the experimental group.

The following section reports on the same quantitative/qualitative comparison for subjects from the control group.

7.7.2 Case reports for some control group subjects

7.7.2.1 Nahida (Indian female)

Although Nahida had not pursued science after Form 4, she claimed to have enjoyed it but focused on Arts subjects because she had hoped to pursue law. Her pre-test score of 60% was above average, however, she failed to improve on this in the post-test with a score of 58%. Once again the evidence from the interview data tended to confirm this outcome.

> **Pre-treatment response to Card 1 - Melting ice**
> I: Could you explain how melting takes place as scientifically as you can?
> Nahida: From its solid state the ice has turned into liquid, that means the ice has lost some of the energy and then it has turned into ice and then finally vapour, that's the third stage. **A.2.12**
> I: Could you say any more about melting at all?
> Nahida: It is one of the process through which solid ice has turned into liquid.
> I: I see. You mentioned that there was some water on the outside of the glass. Could you explain to me where that water has come from and how it got there?
> Nahida: When the ice cubes were placed the glass beaker was dry and due to atmospheric pressure the droplets when the ice has melted was formed outside. **A.2.1**
> I: So you think it has something to do with atmospheric pressure?
> Nahida: Yeah it has to do with that.

Later after mentioning particles in Card 3
I: I see. You didn't mention particles in either of these first 2 cards, could you explain melting in terms of particles?
Nahida: Once the ice cubes they melt the particles contract, they come closer, we can see once its in a solid state it has taken more space but once it has condensed, it's melted it has taken less space, that means the particles have contracted. **A.2.2**

Nahida's initial response showed that she was aware that the concepts of melting and energy change were connected. However, she linked these concepts incorrectly **(A.2.12)**. Her later statement that the ice particles contracted as it melted **(A.2.2)** seemed a logical extension of this initial alternative view. Finally, Nahida associated atmospheric pressure with the process of condensation **(A.2.1)**, but failed to provide a mechanistic link between these concepts.

Post-treatment response to Card 1 - Melting ice
I: Could you explain to me what has happened in this picture and why it has happened as scientifically as possible?
Nahida: We can see the solid ice cubes is started to melt it has gained energy to melt, because to change from one state to another they need energy. Before it was in solid state and now it is turning into liquid and for the third drawing you can see the water droplets outside the glass this is due to the atmospheric pressure. **A.1.5; A.2.1**
I: Could you say anything more about it melting, you said it gained energy how does that gain in energy effect it?
Nahida: Since it has gained energy it has changed its state solid and now it has melted into liquid.
I: Do you know how the energy effects it so that its state has changed?
Nahida: No.
I: I see...this one you mentioned the atmospheric pressure. **A.1.4**
Nahida: Yeah due to humidity the water is very cold because it's ice that has melted, it's cold and due to humidity the water vapour has formed outside the glass.
I: But a minute a go you mentioned atmospheric pressure. How does that effect it?
Nahida: ...
I: If you are not sure about something that's okay.
Nahida: Not sure.

During the post-treatment interview Nahida showed that she was now making the correct conceptual connection between energy change and melting **(A.1.5)**. However, she was unable to incorporate this new conception into a molecular model of melting even though by this stage she appeared to possess all of the constituent conceptions to do so, having mentioned particles in the previous episode. Furthermore, Nahida retained the view that condensation was associated with atmospheric pressure **(A.2.1)**, although later it transpired that this notion may have been due to confusion between pressure and humidity.

Pre-treatment response to Card 2 - Rain Puddles
I: You can see there has been a change between the morning and the afternoon. What has happened between the morning and the afternoon?
Nahida: In the morning it was raining and during the afternoon we can see sunshine.
I: What has happened to the rain and the puddles?
Nahida: The rain, once it was raining we could see the water puddles were formed there and due to the sun's heat, the sun's energy the water has evaporated leaving the ground dry. **A.1.1**
I: Could you describe to me where the puddles have gone and how that actually happened?
Nahida: Part of it must have been absorbed by the soil and then others have been evaporated due to the energy, the source of energy provided by the sun, it has turned into vapour, the air. **A.1.1; B.2.3**
I: Do you know how that process, you mentioned the energy from the sun, do you know how that process of evaporation actually happens.
Nahida: In evaporation the heat is produced and then using that heat the water has gone into the atmosphere.
I: Could you say any more about how it happens?
Nahida: No idea.
Later after mentioning particles in Card 3
I: And could you explain this one in terms of particles?
Nahida: Em due to the heat, the water...the particles have changed into gas now and they've evaporated, they were in the liquid state and now they've turned into gas so now they've evaporated.
I: Do you think the particles change when they move from liquid to gas in any way?
Nahida: In their size.
I: How would they change?
Nahida: It would take up more space probably they would get bigger. **D.2.1**
I: As they change from liquid to gas?
Nahida: Yes.

In this initial episode Nahida was able to explain evaporation at a macro-level, associating it with energy from the sun **(A.1.1)**. However, it was only after particles had been mentioned in another context that Nahida attempted to incorporate it into her original explanation. This attempt at a more scientific construct proved to be unsuccessful, simply revealing a further alternative conception **(D.2.1)**.

Post-treatment response to Card 2 - Rain Puddles
I: Okay...this is the second of the cards, some puddles of water...
Nahida: You can see the sun here...evaporation, the process of evaporation is taken place, that's why we cannot see any water puddles left the energy source was the sun, the sun provided energy so the water evaporated. **A.1.1**
I: Do you know how that evaporation takes place?

Nahida: Due to the energy from the sun, the water puddle formed vapour and they evaporated. **A.1.1**
I: Why does it form vapour?
Nahida: Because it cannot just evaporate as it is water because it's in a pool and it cannot just evaporate so it gets warmed up and then evaporates.
I: Do you know the scientific explanation for evaporation.
Nahida: No.

Perhaps surprisingly, Nahida's post-treatment response to the same card revealed less detail than her first undertaking, with no attempt being made to employ a particle model. Particle models had been discussed as part of the control treatment, but mainly in the context of the text book diagrams provided. This contrasted with the much stronger visual representations of this model presented to the experimental group and consequently most control subjects may not have constructed a well conceptualised particle model as a result of their instruction. This may go some way towards explaining their apparent 'reluctance' to employ such a model in their post-treatment explanation. On the items which related to the two cards reported above, Nahida failed to improve her quantitative performance, achieving only two correct responses out of a possible six on the post-test, compared with three on the pre-test.

7.7.2.2 Salome (Fijian female)

Like Nahida, Salome did not continue with science after Form 4 because she claimed not to like it and had little confidence in her ability. Certainly her pre-test performance of 24% indicated weak content knowledge in the domain of matter and how it changes. Once again this quantitative outcome was confirmed by Salome's pre-treatment interview responses.

Pre - treatment response to Card 2 - Rain puddles
I: This is the morning and this is the afternoon. It's the same place. What was happening in the morning and what has happened in the afternoon?
Salome: In the morning it rains and in the afternoon the sun begins to shine again.
I: And what do you think has happened to the puddles of water?
Salome: It forms...the rain forms those puddles.
I: And what has happened to them in the afternoon.
Salome: Because the sun shines and the heat goes back to the sun...the liquid goes back to the sun. But sun's rays is very strong.
I: And how do those suns rays make the water go back up?
Salome: ...I think by absorbing it...I think.
I: You think the sun's rays...
Salome: Absorb the liquid...the water. **A.2.4**

I: I see could you say anything more about that?
Salome: ...I'm not sure what...I'm not sure.

In this episode Salome equated evaporation with absorption and revealed no understanding of the underlying mechanism which caused this change of state.

Post - treatment response to Card 2 - Rain puddles
I: What has happened to the puddles in the afternoon.
Salome: It has been dried up.
I: And what has caused the drying up?
Salome: The heat of the sun, it absorbs eh...absorbs it up. **A.2.4**
I: How does it...could you say anymore about how that happens, how the heat makes the puddles...
Salome: You know the suns rays it comes down it, absorbs it up makes it drier and then it will again turn into water.

After instruction her view had not altered. The absorption conception had not been reduced in status and was retained unaltered.

When asked to explain the dissolution of sugar (Card 5) prior to instruction Salome was able to state that the sugar mixed with water **(E.1.3)**, although she felt that this process was irreversible **(E.2.2)**. Post-instruction she modified her view on the latter conception **(E.1.1)** but included a new alternate view that the sugar changed to water during dissolving **(E.2.5)** and that saturation occurred because some sugar crystals were too hard to dissolve **(E.2.3)**. Thus it appeared that, during her instruction on solubility, Salome had replaced one alternate view with the scientific view but had also introduced a number of new alternate notions. During the final interview a question arose which had not been asked initially.

I: Let me ask you one other question, why does sugar dissolve...sugar and salt, but if you take sand and you throw some sand in and you stir it, it doesn't dissolve, do you know why that is?
Salome: I think because sugar and salt they're just man made, we just made it you know they're following the process the cycle process you know change from eh solid to liquid, liquid to vapour then back again to solid but the sand it's from eh it's nature it's from God you know we can't change it.

This particular topic had not been covered during the instruction and was a spontaneous question on the part of the researcher. However, rather than suggest that she was uncertain about this, it appeared that Salome spontaneously generated an alternative conception based upon her metaphysical beliefs to deal with this issue.

The following episodes refer to Salome's interpretation of the model lung activity.

Pre - treatment response to the Model Lung activity
Salome: I think the balloon will...the balloon will try to come down too.
I: Do you mean it will blow up, or will stretch down?
Salome: I think it will stretch down
I: OK.
I: When I pull it inflates a bit...it stretches but it stretches out...
Salome: Not going down.
I: So can you think of any reason why it inflates like that...when I pull down on this sheet.
Salome: Because air is...the air pressure is eh...very high?
I: The air pressure is very high?
Salome: Yeah.
I: How is that high pressure created or how does that high pressure work?
Salome: I really don't know.

Post - treatment response to the Model Lung activity
I: When I pull this (diaphragm) down what might happen to the balloon?
Salome: It will em blow up.
I: OK you can try...you were right, could you explain to me why that happens?
Salome: I think air is present inside that's why when you pull this down it will come up.
I: Could you explain to me why that happens?
Salome: I think air is present inside that's why when you pull this down it will come up.
I: Could you say any more about it?...What's it to do with?
Salome I think pressure.
I: Do you know how the pressure effects it?
Salome: I think pressure from underneath...below that causes the balloon to inflate.
I: You mean when you pull this down?
Salome: Yeah.
I: What does that do to the pressure?
Salome: When you pull it down...when you pull this down I think air must have gone inside.
I: Why would that happen?
Salome:...
I: You can't remember?
Salome: No I'm sorry.

In both cases Salome was aware that the activity related to pressure and while she made an incorrect prediction about the behaviour of the balloons in the first instance this had been corrected post-instruction. However, Salome was unable to build on this and provide an explanation which incorporated the scientific principles covered in the course. These had largely been presented as short practical activities or demonstrations from the Basic Science Pupil Book followed by explanations provided by the lecturer. This approach had apparently failed to impact on this particular student.

Overall Salome's post-test score of 38% indicated an improvement in her understanding which was not confirmed by the qualitative data. However, it should be pointed out that, due to circumstances of illness, Salome was only required to complete the objective component of each post-test item with no qualitative justification. This meant that her responses were taken at face value.

7.7.2.3 Salina (Indian female) and Gabrielli (Fijian female)

Salina had completed Biology, Chemistry and Physics at Form 7 (Year 13) level. Consequently, this student had a well conceptualised particle model of matter as evidenced by her initial response to Card 2, the evaporation of rain puddles.

> Salina: The sun is the energy source, so the water in the puddles gets energy and as a result they move apart...the particles move apart and hence rise up in the form of vapour.

By the post-treatment interview she had improved this explanation by making explicit reference to energy gain.

> Salina: The particles in the liquid they gain energy from the sun and as a result they move apart and change into another state that is the gas or air...no, no not just gas...water vapour.

This latter response not only included the notion of particle energy gain (**A.1.5**), which was lacking in the former, but also incorporated the idea of conservation of matter during a phase change (**B.1.1**). Such qualitative improvements were common amongst Salina's post-treatment responses.

> **Pre - treatment response to the Model Lung activity**
> I: What will happen to the balloon when I pull this, will anything happen?
> Salina: It will expand.
> I: Do you know why this is?
> Salina: Its the same as breathing when we breath in the lungs expand it fills with air and when we breath out it contracts the air moves out.
> I: Why does the air move in and out do you know?
> Salina: As soon as you pull that thing at the bottom, the air from the atmosphere is pulled inside I mean the air pressure above here is high so it moves out. **C.2.4**
> I: So you think the air is pulled in?

Salina: Yeah

Post - treatment response to the Model Lung activity
I: When I pull this (diaphragm) down what will happen to the balloon?
Salina: The balloon will bulge out.
I: Why did that happen?
Salina: This happens because when you breathe in our diaphragm flattens and air goes into the lungs...the same thing is shown here.
I: So when I pull this down what happens to make this balloon inflate.
Salina: Air pressure increases inside the body...I mean air fills into the lungs.
I: So when I pull this down does the pressure inside this sealed cavity increase or decrease?
Salina: Decreases.
I: So how does the air get in from outside?
Salina: Since the air pressure inside decreases the air pressure outside is more than the air pressure inside so it pushes the air inside the balloon.
I: Do you know what actually causes...at a particle level...do you know what actually causes gas pressure?
Salina: It is the force of the...eh...it is the force applied onto...onto anything...for example if you heat the thing, heat is supplied to that air and as a result...once you heat something the volume decreases so as the volume decreases the pressure increases.

In both instances Salina's predictions about the model lung were correct. During pre-treatment, although she attributed this to pressure, she implied that the air was sucked in. This view had changed after instruction to that of air being pushed into the balloon. However, her final, rather confused utterance indicated that she, like many of the experimental students had failed to develop a coherent understanding of gas pressure at a molecular level.

Salina's post-test performance of 66% showed an improvement of 14% over her pre-test score. This represented the largest gain by any student from the control group. There was certainly some support for this improvement from the qualitative data reported. Salina clearly started off with a better understanding of matter than most of her colleagues, and this superior foundation may have made it easier to understand explanations provided by the lecturer. However, Salina's performance was atypical amongst control group students. More typical were responses similar to those provided below by Gabrielli, a Fijian male student who had completed Form 7 Biology and Chemistry. These indicated little improvement in understanding even after instruction.

Pre - treatment response to Card 2 - Rain puddles
Gabrielli: The water has been evaporated by the sun

I: How does the sun do that or how does...could you explain to that process of evaporation?
Gabrielli: Usually it em...when evaporation takes place this is wet and this is dry?
I: Yes
Gabrielli: So the sun maybe...it what...maybe it attracts water from when it's come down to earth like this one...and then it goes up to mountains up in the sky and then they form up like eh form into clouds and eventually they fall again into rain when they are heavy. **A.2.4**
I: So how does the sun make the water go up if you see what I mean?
Gabrielli: Oh how does the sun get the water? Maybe due to the what...maybe the hot of the sun...how hot it is that makes the water dry...and also the air also contributes to this.
I: How does the air contribute?
Gabrielli: Because in the air there are...it is very hot that can make it dry make the water dry.
I: I see

Post - treatment response to Card 2 - Rain puddles
I: What would cause that evaporation?
Gabrielli: Heat. **A.1.1**
I: From?
Gabrielli: From the sun.
I: Em how does evaporation work?
Gabrielli: Evaporation it's the heat absorbs the water particles from the environment and then this absorbs it back into the air.
I: So it absorbs the particles...
Gabrielli: Yes the heat takes them up. **A.2.4**
I: I see.

Pre - treatment response to Card 5 - Dissolving sugar
I: So the sugar goes into the gaps
Gabrielli: Yeah it dissolves. **E.1.3**
I: And here some sugar is left even after you stir do you know why that is?
Gabrielli: ...Maybe it just can't...those are hard to dissolve it can't be dissolved. **E.2.3**
I: One other question...could you get the sugar back from this once it's dissolved?
Gabrielli: No I don't think so. **E.2.2**

Post - treatment response to Card 5 - Dissolving sugar
I: What has happened to the sugar in this picture?
Gabrielli: They have dissolved the sugar crystals dissolve.
I: That process of dissolving where does the sugar go when that happens?
Gabrielli: Once you put the sugar, and you stir it the sugar they hit each other and the wall of the container and then it breaks makes it a lot of particles and it's easy to dissolve. **E.2.7**
I: And there are a few crystal left on the bottom why do you think they are left behind?
Gabrielli: These are the particles that cannot dissolve.
I: Why can some not dissolve.
Gabrielli: I'm not really sure.

7.7.3 Summary

While qualitative comparisons are not always conclusive, data presented above tend to indicate that students in the experimental group were generally making considerably more appropriate conceptual connections post-treatment than their control group counterparts. This provided evidence, additional to the test data, of improved conceptual understanding on the part of experimental students in the domain of matter. Most control group students interviewed post-instruction responded in a similar manner to Nahida, Salome and Gabrielli, with little evidence of new knowledge construction and many alternative conceptions appearing to remain unaltered post-instruction. In particular, while experimental students generally attempted to utilise particle theory in their post-treatment responses, control students failed to do this or at best, did so reluctantly and with little apparent confidence. As mentioned previously this may have resulted from the weaker visual representations of matter at the particulate level presented to the control students. Perhaps significantly, control group students interviewed post-treatment recognised that their conceptual understanding of the science topics had not been greatly enhanced.

The final section of results for this study examines the outcomes of a delayed post-test administered to both groups ten weeks after the completion of the teaching experiment.

7.8 Results of the delayed post-test

The delayed post-test was administered in the final teaching week of the college academic year. Due to the proximity to the end-of-year examinations, it was deemed inappropriate to expect the students to complete the complete fifty-item instrument for a third time. Consequently, only eleven of the original items were used (2, 4, 6, 7, 8, 21, 29, 39, 44, 49 and 50). These items were chosen as each had revealed a wide gap in favour of the experimental group on the post-test, and it was of interest to find out if this gap had been sustained. Consequently, it was only possible to compare the scores obtained on the delayed post-test to the same eleven items on the post-test. Nevertheless, this allowed some comparison of comprehension stability for the two groups over a ten week period, an aspect of particular interest in the study as it was anticipated that the quality of learning in the control and experimental groups would differ, and this could produce differential retention of the concepts presented during the intervention. A two-way ANOVA (*SPSS, 1993*) was carried out on the delayed post-test scores for the two groups with the 11-item post-test as covariate (Table 7.3).

Table 7.3.

Comparison of Control and Experimental Group Performance on the Delayed Post-Test, with the 11-item Post-Test Scores as Covariate

Source of Variation	Sum of Squares	df	Mean Square	F
Covariates post-test (11 items)	60.30	1	60.30	33.832***
Main Effects	23.90	2	11.96	6.710**
Group	17.30	1	17.26	9.680**
Race	12.40	1	12.40	6.960*
Group Race	3.13	1	3.13	1.760
Explained	279.50	4	69.88	39.210***
Residual	78.40	44	1.78	

*Note: *indicates significance at p<.05; ** at p<.01 and *** at p<.001.*

Performance on the 11-item post-test was significantly different for the two groups (see Table 7.5; t=6.705, p<.0001), hence the selection of the 11-item post-test score as covariate in this analysis was appropriate. The analysis reported in Table 7.3 revealed a statistically significant difference (p<.01) in the performance of the two groups on the delayed post-test, with the experimental group performing better (see Table 7.4). Thus, on the basis of this performance on these 11 items, the experimental group had maintained their superiority even after the passage of ten weeks.

Table 7.4.

Comparison of Mean Scores on the Delayed Post-Test by Group and Race

Group/ Race	n	mean	SD	SE of mean
Control	23	2.95	1.77	.369
Expt.	26	6.88	2.00	.394
Indian	27	5.56	2.68	.516
Fijian	22	4.41	2.72	.580

Table 7.5.

Comparison of Mean Scores on 11-Item Post-Test by Group and Race

Group/ Race	n	mean	SD	SE of mean
Control	23	3.22	1.95	.407
Expt.	26	7.50	2.45	.481
Indian	27	5.70	2.93	.564
Fijian	22	5.30	3.32	.708

Figure 7.4 plots the pre-test, post -test and delayed post-test scores for both groups and reveals that the rate of change over the ten week period was effectively the same for both groups. As would be expected, test performance on the eleven items showed that both groups had undergone some decline during the ten week period. Interestingly, the superior performance on the post-test by the experimental group was maintained. Given the magnitude of the difference in mean scores between the two groups, it might have been anticipated that the experimental group would have shown a significantly greater decline of content knowledge over time. That this was not the case lends some support to the view that, in general, during the intervention this group was learning with understanding rather than by rote. By contrast, the control group's mean score on the delayed post-test declined almost to the level of the pre-test mean on the 11 items over the ten week period. Certainly Cobern (1996a) claims that rote memorisation involves no interpretation and is rarely meaningful, therefore, students soon forget what they memorise.

Although the analysis revealed no interaction between group and race, there was a statistically significant difference between the performance of the races on the delayed post-test ($p<.05$) although no such main effect for race was detected in the post-test results. Inspection of mean scores (see Tables 7.4 and 7.5) indicated that the diminution which occurred for Fijian students was greater than that for Indian students after the ten week period regardless of the treatment undertaken. While this is a difficult outcome to explain, the proximity of the annual examinations may have been an influencing factor. In general, Indian students, because of cultural pressures to succeed academically, tend to invest more effort in examination revision than Fijian students. This has a historical basis insofar as Indians, despite representing 45% of the total population, own less than 10% of the land in Fiji, thus they view education and particularly the attainment of formal academic qualifications as an alternative form of security. This point was made by the lecturer in science education, herself a Fijian.

> From the point of view of an Indian student, their parents invest so much in their education whereas in the Fijian community I wonder how many parents view education as an investment, because they know they can always fall back on the land if they don't do well. That wasn't my parents' view but I believe many of them still feel that way.

Consequently, it is likely that Indians from both control and experimental groups may have spent more time revising for the annual examinations. This in turn could have boosted their performance on the delayed post-test regardless of the treatment they were exposed to during the teaching experiment.

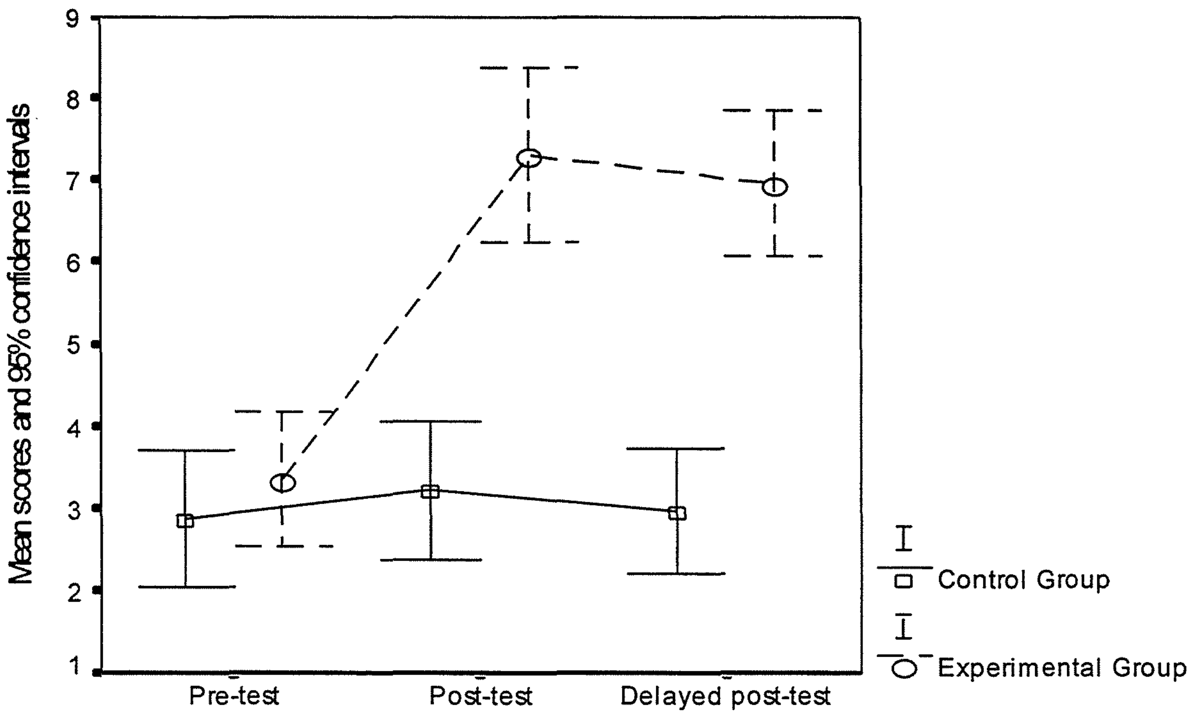


Figure 7.4. The mean scores and 95% confidence limits for the control and experimental groups on the eleven items featured in all three tests (the values have been staggered for ease of reading).

The bar charts presented in Figures 7.5 a and b provide an analysis of data on the scientific response frequencies for the control and experimental groups over the three tests. This allows for a comparison of performance of the two groups on these items over time. (Note the different scales in Figures 7.5 (a) and (b)).

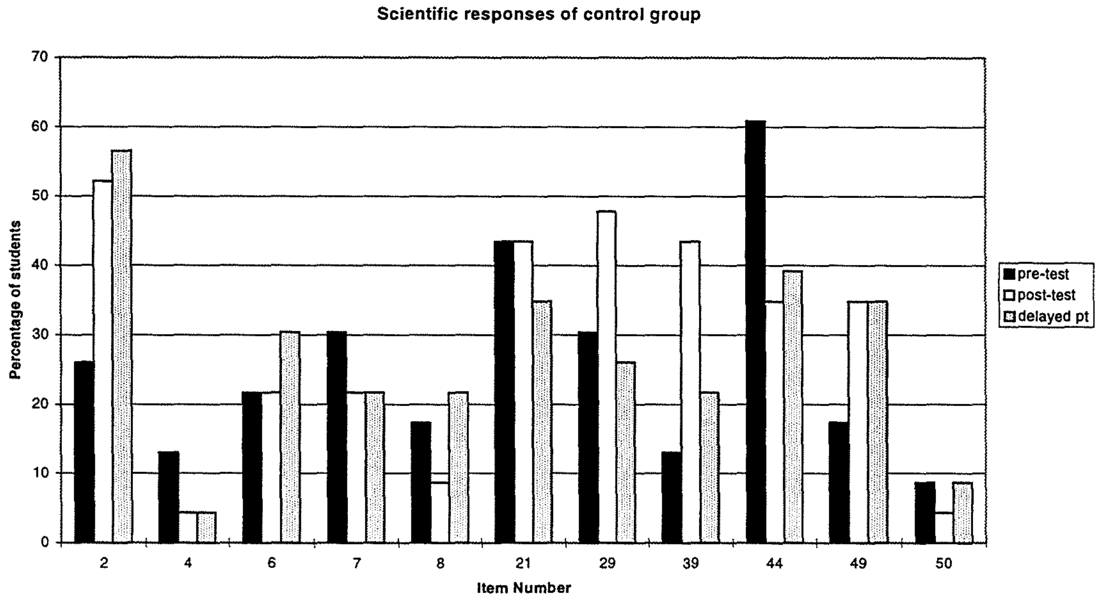


Figure 7.5 (a). The scientific response frequencies of the control group on the eleven items utilised in the delayed post-test.

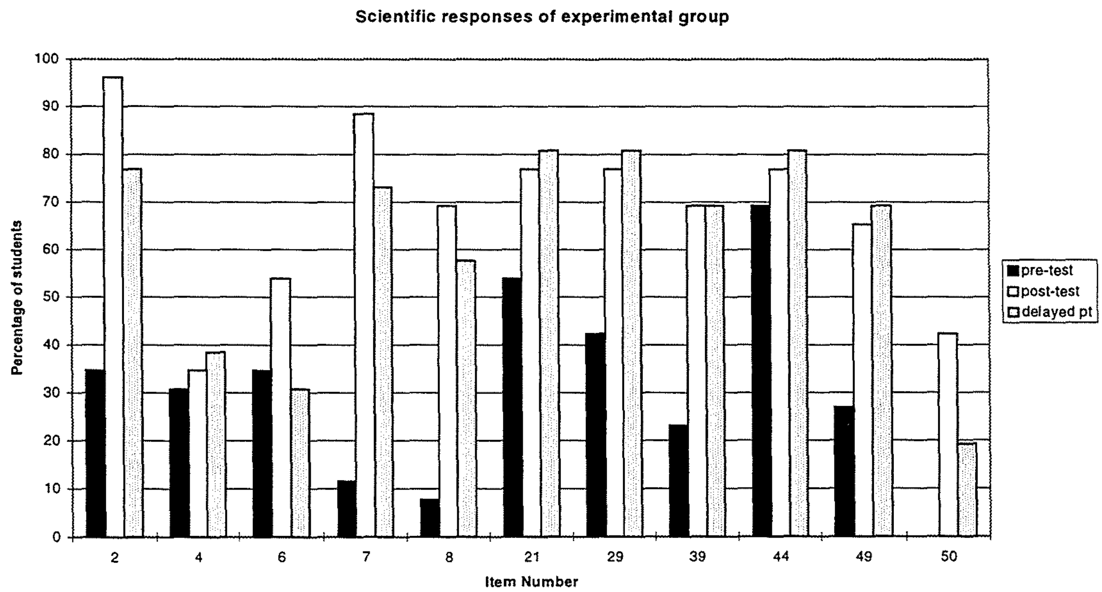


Figure 7.5 (b). The scientific response frequencies of the experimental group on the eleven items utilised in the delayed post-test.

These data show that on items relating to the concepts of conservation of matter and mass such as 7, 8, 21 and 29, the experimental group achieved particularly large gains which were generally well sustained over time. Similar gains were not achieved by the control group on the post-test, with the exception of item 29. The gain on this item was subsequently lost on the delayed post-test. One implication of this difference between the groups may be that, after the treatment, the subjects in the experimental group were more inclined to employ a particulate model of matter when thinking about the concept of conservation. Certainly the use of models and analogies provided them with a strong visual representation of particle behaviour which may have enhanced their understanding of this aspect of matter. Both groups achieved a large post-test gain on item 39 which related to particle behaviour during heating. However, while the experimental group maintained this gain in the delayed post-test, there was considerable attenuation amongst the control group on this item. Once again the strong visual images of particles presented to the experimental group may have helped to maintain the scientific view amongst these subjects.

Although the experimental group made a post-test gain on item 6, which stated that both heat and light energy were required for evaporation, and item 50, which related to heat causing particles to develop a positive charge, this gain had been considerably reduced (item 50) or completely lost (item 6) by the time of the delayed post test. It is possible that the alternative conceptions presented in these items which were appealing to many of the subjects in the pre-test, but had lost status after the treatment, were beginning to regain their status with the passage of time. The pattern illustrated by the control group on these same items was quite different, and difficult to explain, other than possibly representing random fluctuations.

Both item 4, which asserted that humidity was a causal factor in the melting of ice, and item 44 which suggested the presence of air between the particles of a solid, revealed that only small gains had been made by the experimental group over the three tests. Surprisingly, there was a considerable drop in the number of 'scientifically correct' responses amongst the control group. Once again this pattern is very difficult to explain, but it is possible that during the control treatment these alternative concepts had been somehow reinforced or generated in more members of the group.

Finally, both item 2, (which probed understanding of particle behaviour in a solid) and item 49 (on 'living particles') showed a similar pattern for both groups, with gain scores that were largely maintained, although there was some attenuation on the delayed post-test for item 2 for the experimental group. However, for both items the experimental group made considerably larger gains overall. The greater discussion about the nature and behaviour of the particles which was generated during the experimental treatment may have helped these students construct a better understanding of this aspect of matter.

It is important to point out that, due to constraints of time, part of the Evaluation Phase had to be completed between the administration of the post-test and the delayed post-test. As reported earlier in this chapter, it involved revisiting some of the IAI cards and POE activities. Although this exercise involved probing of the subjects' understanding, and offered the subjects an opportunity to reflect on some of the concepts relating to matter, it did not include the introduction of any scientific explanation by the researcher. Since a greater number of experimental subjects were interviewed during this phase, it is possible that this uncontrolled variable may have had some bearing on the outcome of the delayed post-test.

7.8.1 Summary

This chapter has compared the performance of the control and experimental groups on pre-, post- and delayed post-tests in order to determine which treatment was more effective in improving the students' content knowledge and understanding of the domain of matter and how it changes. On the basis of the quantitative data obtained from these tests, the students exposed to the experimental treatment made a significantly greater gain over those exposed to the control treatment. Furthermore, this was maintained over a ten week post-instructional period. In the theoretical context of this study, the results suggest a qualitative difference in the understanding of the experimental students. Data obtained after the teaching experiment seemed to confirm this, with experimental students in general linking concepts more effectively in their construction of explanations when compared with control students.

The students exposed to the experimental treatment proved to be quite effective in articulating their views on the individual teaching strategies and were also quite candid in their views about strategies they found ineffective. Furthermore, control students seemed to be aware of the limitations inherent in their treatment in terms of improving their conceptual understanding of science.

The final chapter examines the extent to which the objectives of the research were achieved and relates the findings of this research undertaken in Fiji to other research in science education in developing countries and, in particular, that aimed at improving students' understanding of physical science.

Chapter 8

Conclusions and Implications

8.1 Introduction

To date the most significant research into science education in Fiji has been that conducted by Muralidhar (1989). He identified many of the existing problems, in particular the need to move away from the ubiquitous formalistic and didactic style of teaching in Fiji, to a more student-centred approach. Although the research reported in this study has been conceptualised quite differently, it does capitalise on Muralidhar's findings by trialing an alternative approach to the teaching and learning of science in Fiji. This involved identifying conceptual difficulties in a specific domain of science, namely matter and how it changes, and developing and implementing a constructivist-based model of instruction in order to address these difficulties. The implementation of this model was ultimately evaluated for its suitability in the Fiji context.

Many of the strategies employed in this model, such as the use of analogies, proved to be entirely novel to the pre-service teachers who took part in the study, and certainly neither the students nor science education lecturers were familiar with the notion of a constructivist view of learning. Thus this approach was highly original in the context of the Lautoka Teachers' College.

The general outcomes of the study, which related to the four objectives outlined in chapter 1, can be summarised as follows:

1. In the domain of matter, there appeared to be little qualitative difference between the alternative conceptions held by Fijian and Indian students, suggesting that the origins of these conceptions were unlikely to be cultural.
2. Alternative conceptions were generally much more prevalent amongst Fijian students than Indian students, as was the level of uncertainty when dealing with concepts.

3. The experimental treatment within the intervention, which was based on a constructivist view of learning, proved to be more effective in improving students' understanding of matter than the more traditional approach implemented with a control group.
4. The instructional strategies employed with the experimental group were generally acceptable to both ethnic groups, despite their cultural differences.

These outcomes are discussed in more detail below. However, although the study was conceptualised around four main objectives, for the purposes of this concluding chapter the outcomes of the objective-related phases have been combined into two groups for ease of discussion. Consequently, the outcomes of phases one and two, largely diagnostic in nature, will be discussed first, while those of phases three and four which focused on the development of a science program to address the alternative conceptions diagnosed are discussed later. In each case, the findings of this study will be related to other work of a similar nature. The implications for the teaching and learning of science in Fiji will also be explored in relation to the research outcomes.

8.2 Phases 1 and 2 - Identifying and determining the types and prevalence of alternative conceptions related to the domain of matter amongst pre-service primary teachers in Fiji

The initial phase revealed that pre-service primary teachers in Fiji held a wide range of alternative conceptions in the domain of matter and how it changes, many aspects of which they must cover if they are assigned to teach Years 7 or 8 within the primary system. While many of these alternative views related to concepts underpinning the content to be taught, rather than the material delivered directly to primary students, it should still be a cause for concern for education authorities in Fiji. As Kruger and Summers (1989) point out, it is difficult to see how children can be correctly guided along an experiential path leading to understanding of changes in materials and the associated role of energy unless the teacher guiding them has some deeper understanding of the processes involved. Furthermore, as Carré (1993) suggests, children may wish to discuss certain issues in greater depth than that covered in the lessons, but it would appear that many student teachers could encounter difficulty doing so. While Carré was referring to the UK context, the same would appear to hold true for Fiji. Certainly there was some evidence from this study that alternative conceptions may have been passed on to Fiji students as a direct result of teachers' limited conceptual understanding of physical science.

One finding of particular interest was the strong qualitative similarity between the alternative conceptions held by Indian and Fijian students which, in fact, could be extended to include the Australian students who took part in the pilot studies. Despite some differences in the finer details of internal structure, the Concept Profile Inventories for each of these groups were generally very similar despite the students' diverse cultural backgrounds. In fact the conceptions elicited from all three cultural groups were consistent with those presented in the alternative conceptions literature relating to the topic 'matter.' For example, students from all three cultures confused observable properties of substances with the properties of molecules, and attributed changes in substances to changes in molecules themselves, a finding similar to that presented for American elementary school students by Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993). Furthermore, many of the subjects in Fiji believed that gas has no weight, or that gas is lighter than the liquid from which it was obtained, while others viewed melting as an integral part of dissolution. Once again these views were similar to those recorded by Stavy (1988) and Ebenezer and Erickson (1996) respectively amongst Western students.

Nevertheless, there were certain differences between the two cultures in Fiji, with Fijian students more likely to dwell on the surface features of the problems presented, demonstrating a greater reluctance to apply a particle model than Indian students, even when it became apparent that they did possess such a model. In this regard the Fijian students tended to behave more like novices as described by Chi, Feltovich and Glaser (1981), than the Indian students in the sample, who in general were more likely to consider the underlying scientific principles involved. However, it is quite likely that this was due more to differential schooling in science, rather than any cultural difference. As mentioned previously in chapter 6, a considerably larger proportion of Indian than Fijian students had pursued post-compulsory science at high school.

While, from a cross-cultural perspective, the results of this study indicated the similarity of types of alternative conceptions, there was a considerable difference in their relative prevalence or frequency across the two groups. The Indian students usually exhibited higher frequencies of the scientific conceptions and lower frequencies of the alternate conceptions than the Fijian students. This was particularly true for survey items which required reference to a particulate model of matter which, as mentioned above, Fijians either lacked or showed a reluctance to apply.

There is little corresponding literature on the relative frequencies of alternative conceptions across cultures because, as Thijs and van den Berg (1995) point out, frequencies may differ for a particular level of education or age of the students. Thus it is not easy to compare frequencies across countries, unless it can be ensured that the student samples to be compared are matched in educational terms and between countries. Such matching is next to impossible. Although Fiji offered a situation where both cultural groups had been exposed to the same educational system, and while the college entry requirements screened students with roughly equivalent academic achievement, there was the problem referred to earlier of differential schooling in science. Fijians in general are somewhat less likely to pursue senior high school science than Indians. Thus, observed differences in the prevalence of the alternative conceptions between the Indian and Fijian students, may be derived from different cultural backgrounds, different amounts of formal study of science at school, or a combination of such factors.

In terms of motivation, there was also some contrast between the findings of this study and those reported in a Western context by Kruger and Summers (1988). Whereas Kruger and Summers found that English in-service primary teachers generally expressed a strong desire to resolve anomalies in their thinking about science, this was not as apparent amongst the pre-service primary teachers in Fiji. They appeared to be unaware or unconcerned about inconsistencies and contradictions in their responses, something which is more consistent with the findings for school-age children (Kruger & Summers, 1988). This may in part have been due to the different levels of experience exhibited by the two groups, as Kruger and Summers worked with relatively experienced in-service primary teachers, while the cohort in Fiji were pre-service and mostly came to the teachers' college directly from high school.

Furthermore, Gunstone, Champagne and Klopfer (1981) and Champagne, Gunstone and Klopfer (1985a) suggest that trainee teachers place a higher premium on the understanding of science than do high school students, because the trainees will have to teach the concepts themselves and thus the advantage to them of the intellectual struggle of understanding is greater than that perceived by high school students. In Fiji the need amongst primary teachers to understand scientific concepts may be less than in Western countries as the primary curriculum is strictly prescribed in the Teacher's Guide and Student Book, with set activities and teacher's notes. Muralidhar (1989) pointed out that strict adherence to these texts was commonplace in Fiji. Consequently, teachers in this context may well place a lower premium on the understanding of content knowledge as they perceive that they can fall back on the text when problems arise. Certainly a number of student teachers commented during interviews that "it would be difficult to go far wrong in science as long as you had the Teacher's Guide to help you."

The apparent commonality in conceptions amongst students from diverse cultural background, reported here, would seem to be in direct conflict with the assertions of Jegede and Okebukola (1989) who contend that traditional beliefs interfere with the learning of science, as the younger members of traditional societies grow up to learn and believe the traditional views without question. This ultimately creates conflict when individuals experience school science which presents opposing views of the world to that presented by their elders. The study in Fiji found that this was not the case, at least within the domain of matter. Significantly perhaps, there appeared to be no corresponding belief system about the nature of matter existing within the traditional cultures in Fiji. Even when students were asked explicitly if they could think of any traditional beliefs which ran counter to the teaching they had received on matter, they were unable to do so. In addition, when an unusual view was expressed, it was normally held by a single individual, suggesting a personal construct rather than a socio-cultural one.

It was noteworthy that the data from the prevalence phase supported those obtained during the elicitation phase, by confirming the commonality of alternative conceptions provided by both ethnic groups. Thus, both the intensive interview data and the quantitative survey data led to the same conclusion, that there appeared to be no major cultural influence on the development of alternative conceptions about matter.

The findings of the Fiji research tend to support the argument presented by Thijs and van den Berg (1995) who claim that the domains of physical science and tradition do not overlap and, as such, traditional beliefs should not exert hindering influences on the acceptance of scientific explanations. They cite a number of domains such as heat and temperature, light and electricity where cross-cultural research, which included traditional societies, has revealed very similar alternative conceptions. Furthermore, Albanese and Vicentini (1997) found that alternative conceptions about the particulate nature of matter amongst Italian students were qualitatively identical to those reported for students in England and the USA.

It may be dangerous to generalise too far regarding the lack of overlap between the domains of physical science and tradition. Certainly, Lynch and Jones (1995) claim to have found an alternative view of melting amongst Filipino students, which they attribute to their rice/water culture. However, no connections of this nature were found in the Fiji study reported here.

This outcome in Fiji has certain implications for the teaching of matter and how it changes. Clearly, if students from both cultures hold similar alternative conceptions, they should both be developing their understanding from a similar qualitative baseline. In addition, as there appeared to be no parallel traditional belief system about matter amongst the student teachers in Fiji, there seemed to be little risk of portraying the Western scientific view, even implicitly, as *the* way of viewing this topic (Jegede, 1995). Certainly, a number of authors (e.g., Krugly-Smolska, 1996; Ogawa, 1986, 1995) have argued that the implicit assumption in science education that Western scientific views are superior to traditional beliefs may alienate students from traditional cultures. The fact that this is unlikely to occur when teaching about matter in Fiji suggests that instruction, in this domain at least, will not impinge upon cultural sensitivities or belief systems.

The statement above should not be interpreted as establishing the appropriateness of portraying the scientific view of matter as the only view in the context of Fiji. Quite the contrary, as clearly these students held many alternative conceptions of matter which must be dealt with sensitivity. As Driver (1989) has stated, insistence upon conceptual change should not come at the expense of the learners' confidence, because maintaining the learners' confidence in themselves as capable of making sense of their experiences is essential to the learning process. Nevertheless, the apparent lack of a traditional view of matter in Fiji may suggest a less complex conceptual ecology amongst the learners than might otherwise be the case, and consequently make the introduction of new scientific ideas less problematic.

Thijs and van den Berg (1995) argue that, although culture does not seem to be responsible for strong physics preconceptions, they did expect cultural influences in the formation of certain other preconceptions, mainly biological ones. Once again this notion appeared to be supported by the outcomes of the Fiji study, as when students from both cultures were asked about traditional views which ran counter to the Western scientific views in other domains they were able to provide a number of examples.

In matters such as health, subjects from both cultures could provide examples of traditional beliefs which are clearly at odds with the Western scientific view and, as such, result in potential conflict with school science. Furthermore, almost all Indian and Fijian subjects interviewed rejected the scientific view of human existence resulting from organic evolution. In this instance the conflict was not related to traditional beliefs but to fundamental religious beliefs.

As mentioned previously in chapter 6, it is difficult to explain why some domains of science, particularly physical science offer little potential conflict with traditional beliefs while, for other domains, there are clearly conflicting viewpoints which could result in confusion for the learner. Perhaps much of physical science comprises domains of knowledge which are sufficiently abstract that traditional cultures never developed a widely held alternative belief system of their own, resulting in a lack of interference between domains. Thus alternative conceptions which do arise may be instructionally derived, because school is the only exposure students get to these aspects of science. This would help explain the consistency of alternative conceptions across the three different cultures in this study. As Thijs and van den Berg (1995) point out, in cross-cultural comparisons of students, one deals with subjects who have studied or are studying science in school from books and with methods which are very similar across countries. These authors go further in their assertions about alternative conceptions, claiming that they may be inborn and/or triggered by sensory experiences. They contend that the educational starting position of students entering schools in various cultures are very similar as far as their preconceptions in physics are concerned. However, the research reported here was not designed to shed further light on this issue.

In less abstract areas of science such as issues of health which individuals are likely to encounter on a regular basis, alternative belief systems may develop much more readily amongst traditional societies, and often these do conflict with the accepted scientific view. Thijs and van den Berg concur, arguing that biological conceptions on growth, health and illness etc. are often constructed out of cultural repertoires and are therefore idiosyncratic.

In relation to health, the students in Fiji exhibited the ability to distinguish between school science and the domains of traditional beliefs and were clearly aware that it was unacceptable to present traditional views in the context of school or national science examinations. Despite this, many students held their traditional beliefs in high regard. While Jegede's (1995, 1997) model of collateral learning and Dart's (1971) notion of conceptual dualism attempt to explain this ability, in light of this study they may not be expansive enough to account for the findings. These dualistic models restrict themselves to the interaction between traditional thought and

Western thought or more specifically Western scientific thought. Like Vlaardingerbroek (1991), this researcher would point to the limitations of such models for not including or making explicit the influence of Western religion. In the context of Fiji the predominance of fundamental Christian thinking would appear to have more influence over the acceptance of certain scientific concepts amongst the majority of Fijians and also some Christian Indians, than traditional beliefs. Certainly when a student views the formation of a rainbow as a Biblical event and fails to consider the underlying science, it points to the strong influence of Western religion. Thus Vlaadingerbroek (1991) who viewed conceptual dualism as an oversimplification of the conceptual ecology of educated Papua New Guineans proposed a conceptual triangle as his preferred model. This he argues would have traditional beliefs/Western science/Western religion at its apices, with potential or actual tensions running along all three sides of the triangle. In Fiji the situation is more complex than in Papua New Guinea as three major religious groups exist, Christians, Hindus and Muslims. Each of these religions presents dogma which may be in conflict with some aspects of science. Thus the term fundamental religion is more appropriate than Western religion in the context of Fiji.

Although an advance on the dualist models, Vlaadingerbroek's conceptual triangle still fails to account for certain other factors which may influence the conceptual ecology of students of science from traditional cultures. Thus an alternative model is proposed here (Figure 8.1), which, although quite different in approach, is more appropriate over a wider range of situations.

This model may provide science educators in traditional or multicultural settings with further insight into the complexities facing students of science in these contexts. Thus it incorporates the same three idea systems as those described by Vlaardingerbroek (1991) i.e., 'Science', 'Religion' and 'Traditional beliefs', but treats them as *influences* in the conceptualisation process rather than as systems in which ideas of a particular domain may simultaneously reside. Also part of the model are 'Other influences' - these encompass such things as ideas from other cultures and explanations from sources, such as school instruction, that do not correspond with the other categories. These four sources of influence are external to the individual. The model indicates that the individual processes information from various sources and that the processing can include misconceptions or misunderstandings of the information. Finally, at the centre of the model, is the result of the individual's internal processing, a personal conceptualisation that is used to explain the observed phenomena under question. In different circumstances and with different individuals each of the external sources will have varying influences, as will the possibility for misconception in the internal processing.

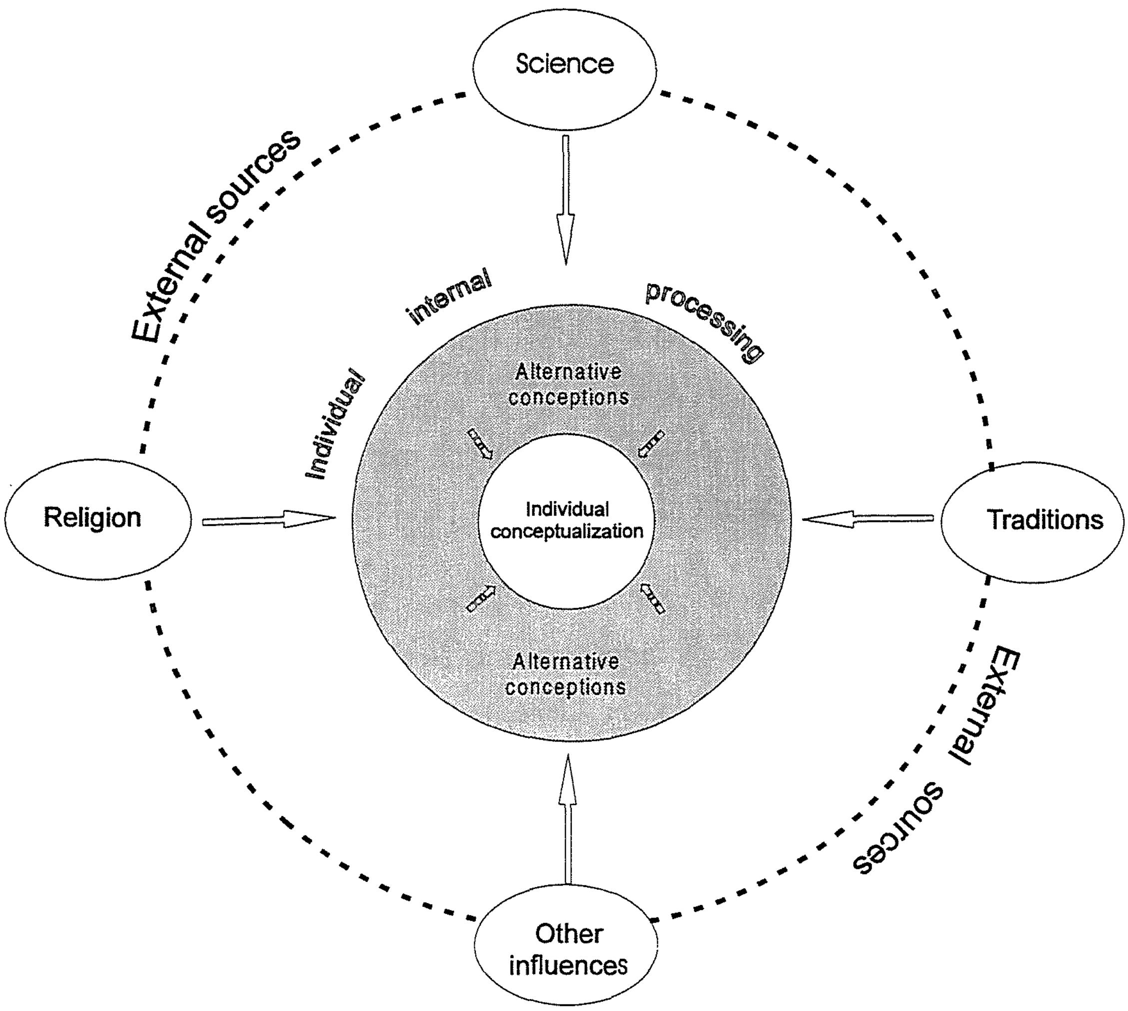


Figure 8.1. Model of the process by which individuals may reach their own personal conceptualization of observed phenomena (Taylor & Macpherson, 1997).

This relates to, and to some extent expands on, the concept of a 'cultural filter' proposed by Jeans (1974) by identifying specific elements of the 'filter' which may influence an individual's perception of the 'real environment'. As Jeans suggests it is only by studying the 'filter' that the observer is able to explain particular options and actions on the part of the group being studied.

The cumulative effect of the individual conceptualisations, over many domains of learning, is the person's understanding of the natural world - conceptual dualism being an artefact that may arise from these processes under certain conditions, e.g., when the influences of both science and religion are strong but in conflict regarding a particular domain. In other circumstances it is possible that more than two influences may interact. For example, a Hindu student may have conflict or tension between his or her religious belief in reincarnation and the theory of evolution, while at the same time constructing a number of alternative conceptions about this theory during instruction.

Regardless of the model, however, contextualisation of knowledge seems to be the mechanism employed by many individuals as a means of coping in a society where they are influenced by a number of different systems which explain physical phenomena. Ogunniyi (1988) makes the important point that although students may enter science classes with a traditional cosmology that is not acceptable to Western science, it does not preclude an understanding of science. This view finds support from other authors (e.g., Aikenhead, 1996; Cobern, 1996a) who argue that students can understand the sub-culture of science without integrating it into their life-world.

Such a situation appeared to hold true in Fiji where students often claimed that they did not believe certain aspects of science but still appeared to understand them and even find them interesting. Furthermore they did not exhibit any overt hostility to theories that they perceived to be in direct contradiction to their often deeply held religious or traditional beliefs. This suggests that conflicting belief systems may not be as detrimental to the learning of science in traditional societies as some authors claim.

When the Fiji students' views on the nature of science were elicited they presented what appeared to be a rote learnt definition from their school days that science was the study of living and non-living things. Nevertheless, when probed further there was no indication that they viewed science as a way of knowing. Rather most revealed an absolutist view of science as being able prove things to be true and irrefutable. This view was common amongst both ethnic groups. In general, Fijian students were more likely to believe that only above average students could do well in science, perhaps reflecting their lower success rate in science compared to Indian students.

Although this investigation into students' views on the nature of science represented only a minor part of the overall study it did suggest that absolutist views of science may be common amongst students in Fiji. This is not surprising given the formalistic manner in which science is taught in many schools together with the dogmatic nature of both religious and political thought so prevalent in Fiji. In such an environment, relativist thinking is unlikely to be accepted readily or even understood. However, in comparing these limited findings for Fiji with Lederman's (1992) extensive review of research on students' and teachers' conceptions of the nature of science, the absolutist views expressed by Fiji students appear to have much in common with those expressed by their Western counterparts.

Although students' views on the learning environment contained a number of quite traditional notions particularly in regard to classroom competition and the desirability of a large number of summative examinations, there was a sense that the students were also receptive to more innovative approaches to teaching. Both Maddock (1982) and Lake (1993) have commented on this openness to new experiences amongst students in Papua New Guinea. Maddock has suggested that this is associated with the assertion of increasing independence from authority of traditional figures, and a belief in the efficacy of science and medicine and the abandonment of passivity and fatalism. These authors regarded modernisation and urbanisation as the key factors contributing to these attitudinal changes.

Certainly change in Fiji, a country which up until mid 1991 had no television service, is currently taking place very rapidly. Many of the indigenous Fijian students interviewed came from urban homes and had relatively little contact with village life, with a resultant weakening of traditional influences. A number of students also commented on the attitudinal changes amongst children and the extent to which they were now prepared to ask questions and request clarification from their teachers rather than simply accepting all the information given. For better or worse these changes may be producing an openness to new thinking which might provide better opportunities for those wishing to implement educational change.

In summary, the first two phases of the research indicated that students in Fiji held a wide range of alternative conceptions about matter which were prevalent throughout the student population of the college. These conceptions were very similar across the two main ethnic groups and to those held by Western students, indicating that they did not appear to derive from an interaction with traditional beliefs, possibly because no corresponding view exists within the traditional belief system. However, in other domains such as health, strongly held traditional views may exist and conflict with equivalent scientific views. Understanding the effects such conflicts have on students will be of considerable importance for those involved in science teaching in Fiji and other countries with traditional societies.

Views on the nature of science were generally absolutist, but possibly no more so than for Western students, while there appeared to be a receptiveness to new teaching strategies.

A major implication of these initial findings is the possibility that a teaching program based on pedagogy derived from a Western context might be effective in promoting a better conceptual understanding of the scientific domain of matter, despite some criticism of the direct importation of Western pedagogy, particularly conceptual change pedagogy, into developing countries (e.g., Cobern, 1996a; Taylor, 1994). Such criticisms focus on the notion that teaching for conceptual change might serve as an agent of Western cultural imperialism by devaluing the integrity of students' traditional beliefs.

However, in the research reported here, particularly in chapter 7, there was evidence to suggest that certain teaching strategies derived from the West could prove effective in the Fiji context. Conclusions and implications of this part of the present research are presented in the remaining sections of this chapter.

8.3 Phases 3 and 4 - Designing, implementing and evaluating a teaching program aimed at improving the students' conceptual understanding of matter and how it changes.

Baker and Taylor (1995) state that, although many of the learning difficulties of non-Western students have been highlighted in the literature, few attempts have been made to understand how non-Western students might better learn science. It was the intention that this research project should provide further insight into this problem by developing a teaching program, conceptualised within a constructivist paradigm, and evaluating its outcomes both in terms of improved conceptual understanding and its overall acceptability to students from culturally different backgrounds.

The findings from the initial phases indicated that some of the problems concerning the direct importation of Western pedagogy into non-Western countries may not be a direct issue in this instance. For example Taylor's (1994) belief that in a non-Western context, conceptual change pedagogy might serve to acculturate students into a dominant and monocultural Western scientific view which requires them to relinquish their own traditional beliefs was not supported. The conceptions the students held regarding matter did not appear to be culturally grounded. However, due care was taken not to devalue the alternative conceptions exhibited by the students as this, it would appear, can cause a loss of confidence amongst students regardless of culture. Consequently, the use of teaching strategies based solely on conflict was kept to a minimum.

Baker and Taylor (1995) and Cobern (1996a,b) believe that a constructivist approach to teaching and learning is an appropriate way to proceed as long as the strategies employed are not imported directly into the science classrooms of non-Western schools without an examination of their potentially problematic features. In this study only strategies believed to be culturally appropriate for Fiji were employed.

The overall intention was to expose students to a series of novel learning experiences which engaged them actively in the hope that they would achieve an improved understanding of matter and how it changes, and would be more challenged by the approaches involved than those generally employed in the teaching of science in Fiji. The outcomes of the research were encouraging for science education in Fiji because, not only did the students from the experimental group show an improvement in understanding about matter, but also members of both ethnic groups appeared to find the constructivist-based strategies interesting and culturally acceptable.

Research of a similar nature conducted in the UK by Summers and Kruger, (e.g., Summers, 1992) which employed pedagogy derived from Constructivist Theory with pre-service and in-service primary teachers also offered encouraging results. Nevertheless, Summers cautioned that it was important not to read too much into outcomes based solely on test results as it is possible that a proportion of correct responses reflect memorisation of course content with little real underlying comprehension. Consequently, he called for the use of more sophisticated evaluation techniques.

To some extent this problem was overcome in the present study by using post-intervention interviews in an attempt to confirm the quantitative findings. These appeared to verify that many of the students, both Indian and Fijians had developed real comprehension, given the way in which they could incorporate new concepts into their existing schemas appropriately, and apply particle theory to many of their explanations after instruction.

Although Rollnick's (1988) study in Swaziland also employed pedagogy derived from Constructivist Theory it proved inconclusive in terms of improving student teachers' understanding of pressure. Rollnick largely utilised a single conceptual change strategy, that of conceptual conflict through the implementation of the Conceptual Change Model (CCM) (Hewson, 1981) which may not have been culturally appropriate. Furthermore, pressure seemed to be the topic with which students in Fiji had most conceptual difficulty. It may be that the topic of pressure requires more time than allocated by Rollnick or in the present study.

In contrast the outcome of the Fiji study appeared to be more successful, possibly because, like the work of Summers and Kruger (1994), it employed a wider range of strategies based on Constructivist Theory which were largely continuous in nature (Duit, 1994), building on the learners' existing ideas, rather than a discontinuous strategy as employed by Rollnick (1988). Furthermore, it is quite likely that the level of English amongst Fiji pre-service primary teachers is superior to that of Swaziland pre-service teachers.

However, Rollnick and Rutherford (1993) did comment that the use of the CCM promoted lively discussion in the classroom when compared to the more traditional teaching approach. Certainly one characteristic difference between the teaching as observed in Western and non-Western classrooms is the degree of students' participation. Many non-Western teachers give information of facts and principles and the students listen. The amount of time spent on application of principles and problem-solving is generally less than in a Western classroom (Thijs & van den Berg, 1995). The Fiji project offered students more engagement in their own learning and the opportunity to apply principles and concepts to explain problems. Consequently, as with Rollnick's study the experimental group in Fiji engaged in much more argument and discussion than those students taught in the traditional manner.

Other authors who have reported on conceptual change studies (e.g., Shymansky, Woodworth, Norman, Dunkhase, Matthews, & Chin-Tang, 1993; Summers & Kruger, 1994) have claimed that conceptual change is rarely straightforward. For example, Summers and Kruger (1994) claimed that training based upon strategies generally considered to be good practice could substantially improve primary teachers' understanding of science concepts. However, in many cases the scientific understanding achieved was likely to be partial and 'messy' with alternative conceptions co-existing alongside scientific views and teachers unsure of their new knowledge. Furthermore some individuals progress at a greater rate than others, and some concepts are more easily acquired than others. Gunstone and Northfield (1994) also argue that conceptual change rarely involves complete abandonment of one notion in favour of another. Rather they claim it often involves the addition of new notions with the retention of existing notions.

Very similar outcomes were achieved in Fiji to those mentioned by Summers and Kruger (1994). Although it could be claimed that the experimental group made an improvement in their overall understanding of matter, some individuals progressed more rapidly than others, a factor which did not appear to be related to race, gender or even educational background. Furthermore, understanding of topics such as heat and conservation of matter seemed to improve more readily than understanding of pressure during the experimental treatment. Individual students also exhibited inconsistent views both in their post-test responses and the post-treatment interviews, while some students were still unsure about applying particle theory to their explanations compared to others who had become confident in this area.

The post-intervention interviews and delayed post-test results revealed that a number of students seemed to have regressed in their understanding. This was particularly true of students who embarked on the treatment with a very poor understanding of matter as judged on the basis of their pre-treatment test score and/or pre-treatment interview performance, but who achieved a large improvement on the post-test. Although this apparent regression may have been due in part to a lack of any revision before the delayed post-test as mentioned in chapter 7, it could also indicate that a strong component of rote learning may have taken place during the intervention. Certainly these students who started from a very low conceptual baseline may have lacked a sufficiently well developed conceptual ecology in this domain to link in many of the new concepts successfully. Consequently, they may have relied on rote learning as their strategy for coping. However, because the study in Fiji was of relatively short duration it was not clear whether the regressions exhibited by these students were enduring or intermittent. Clearly this would have required closer monitoring of these individuals over a longer time period. According to Shymansky et al., (1993) a constructivist interpretation would suggest that intermittent regressions can precede conceptual framework restructuring, and therefore apparent regressions in understanding should not only be expected, but also may actually signal that positive restructuring is imminent. However, it should be pointed out that Shymansky and his colleagues were making these comments during an extended treatment which involved very close monitoring of individuals at the time of instruction, rather than post-treatment.

The evaluation phase indicated that some of the teaching strategies were more popular with the students than others. The use of analogies and models was a particularly popular strategy as it offered the students strong visual representations of particle behaviour, and a number of students commented on the benefits of actually seeing how the particles behaved in relation to energy inputs and outputs. Furthermore, students commented that the analogies presented were familiar and easy to understand, thus presumably making it easier for them to link unfamiliar abstract concepts to the relatively familiar analogies. There was evidence that analogies are used in Fiji in the teaching of science, but their use is not widespread. Of the only two examples students could recall from their teaching, one, that of portraying condensation formation as analogous to sweating, is misleading and was taken literally by a number of students.

There appears to have been very little research on the use of analogies in developing countries but a recent study by Jegede, Lagoke and Oyebanji (1995, unpublished manuscript) on senior secondary school students in Nigeria has indicated the effectiveness of using environmental analogs in developing very positive attitudes towards biology and to the use of this method of instruction. Certainly, in Fiji, although no instruments were used to measure attitude, it was clear that the analogies used, although they were developed in the West, were a popular form of instruction for both ethnic groups. There was also no evidence of the students taking the analogies too literally in this study, a problem referred to by Treagust (1993).

Jegede et al. (unpublished manuscript) believe that analogies seemed to have enhanced greatly the imaginative abilities of students, and in particular low achievers, in their sample and ultimately helped them to cope adequately with understanding the biology concepts taught. While no such claims could be made of the Fiji study, the use of effective analogies appears to offer the potential for making science more interesting and relevant to students and this is an aspect of the study worthy of much more research.

Collaborative group work also appeared to be a promising strategy for use in the Fiji context. There was evidence from the discourse provided by various groups that the students were prepared to engage in discussion and argument about the practical problems provided. Furthermore, the groups often showed considerable persistence in attempting to construct an explanation which they perceived as satisfactory for the problem in hand. This was extremely encouraging as most of the students involved had not been exposed to this form of group work during their previous educational careers. Once again it appeared that, given the appropriate background information as well as sufficient scaffolding, Fiji students can be encouraged to think critically. Certainly this situation contrasted sharply with that described by Muralidhar (1989), where, for the most part, students were observed performing practical activities in a context which required little or no recourse to critical thought.

One important feature of this strategy was the requirement for resources, an aspect of science instruction which teachers sometimes claim constrains their science teaching (Muralidhar, 1989). Throughout this study only the most basic everyday materials were employed and it was made clear to the students that simple problems could be devised without the requirement of sophisticated materials.

Some teaching and learning strategies were less attractive to the students. For example the use of concept mapping as a learning device was received with some ambivalence. While Jegede, Alaiyemola and Okebukola (1990) found that the use of concept mapping with Nigerian students was significantly more effective than traditional expository teaching in enhancing learning in biology, no similar claim could be made for this study. The Fiji study was based on more than a single variable and because of this it was not possible to provide a large amount of time to instruction on the construction of concept maps. Thus, while as part of the project conducted by Jegede et al. (1990) the students received three weeks of instruction in concept mapping strategies prior to the start of the research, it was only possible to afford the Fiji students two single hour sessions. Furthermore, due to constraints of time within the treatment, the students were unable to complete a third and final concept map on matter.

Jegede et al. (1990) claimed that, as concept mapping represents a kind of metacognitive strategy, it overlaps with the constructivist view of learning in which individual learners generate their own understanding of the concepts being taught. Using concept maps allows the learner to make decisions about the ‘hows’ and the pace of what is learned and confers on the learner the advantage of shaking himself/herself free from the pressures which otherwise impede meaningful learning. Having said this Jegede et al. (1990) caution that their research was based on a small one sample design, while the probable effects of confounding variables may have jeopardised the external validity of their study. Consequently, they recommend cautious interpretation of their conclusions.

Nevertheless their generally positive findings in the context of a developing country along with the favourable response of some of the experimental students in Fiji suggest that concept mapping may well offer an effective teaching and learning tool given more time to instruct students in the construction of the maps. Certainly, this would appear to be another aspect of the project worthy of further research.

Finally, one of the more disappointing aspects of the study was the limited recall students had of the simple introduction to constructivism they received at the beginning of the intervention. As mentioned in chapter 7, only one student appeared to have any memory of this and even she required some prompting. It is possible that the researcher did not ask the appropriate questions when attempting to elicit a response on this issue. Clearly there was also the possibility, at the initial stage when this theory was being discussed, that the students were suffering from information overload and failed to grasp the theory effectively. However, it is also likely that students in Fiji give little thought to their learning processes as so much emphasis is given to the outcomes in terms of examinations regardless of whether the learning is meaningful or not. This may also help explain why concept mapping was not embraced with great enthusiasm.

As mentioned previously, given the poor recall of the constructivist view of learning it seemed unlikely that there was the kind of metacognitive development in terms of the students' own learning processes that was claimed by Summers and Kruger (1994). However, unlike Summers and Kruger study, this research was dealing with a less mature group of students and more time to discuss constructivism may have been required in order to make a lasting impression on the students in Fiji.

8.4 Implications of the study

There are a number of implications which arise from this study. It would appear that in some aspects of physical science there may be little need for further research into alternative conceptions held by students in developing countries as these are not likely to have cultural roots and should vary little from those presented in the alternative conceptions literature. Students from both major ethnic groups in Fiji are generally receptive to teaching strategies based on a constructivist view of learning, and are unlikely to resist these regardless of their cultural background. It seemed that, when provided with an alternative science learning environment to the traditional expository model, students in Fiji are likely to express themselves more readily and therefore increase the opportunities for developing critical thinking skills which, at present, are often sadly lacking even at the tertiary level (Taylor, 1993). It may be that small changes to curriculum materials relating to matter, such as the introduction of suitable analogies, could have a considerable impact on the students' ability to conceptualise a particulate model of matter. Certainly, there was evidence that some of the diagrams in existing textbooks were unclear or misleading, and did little to assist students in constructing a robust molecular model. Although some students arrive for primary teacher training with a weak understanding of science, exposure to instruction which is sensitive to their needs may go a long way towards improving this situation. Such an approach seems more likely to be effective than one based on going through the prescribed texts lesson by lesson. Finally, exposure to science teaching strategies rooted in a constructivist approach to learning, may, over time, help reduce the disparity in performance which presently exists between Fijian and Indian students.

8.5 Recommendations

On the basis of this research and the wider research literature, it is possible to make a series of specific recommendations regarding the teaching of science at Lautoka Teachers' College and Fiji schools along with suggestions for future research. These are as follows:

1. That further research on the individual teaching strategies described in this study take place in order to ascertain their effectiveness in different contexts within the education system in Fiji.
2. That LTC develop a series of topic-based courses in science which cover the material taught in primary science, and employ strategies derived from a constructivist view of learning. These should be trialed and evaluated with a view to implementation.
3. That science lecturers at LTC be given in-service training in constructivist approaches to the teaching and learning of science as, at present, they have no background in constructivist epistemology, despite its influence on science pedagogy elsewhere.
4. That teacher education institutions provide instruction on the production of test and examinations items which assess higher order thinking.
5. That during the next revision of the school science curriculum considerable attention be given to the quality of diagrammatic material presented.
6. That student and in-service teachers receive instruction in the production and use of low cost models and equipment which help to demonstrate scientific concepts effectively.

It would be unrealistic to call for the full scale introduction of teaching strategies based on a constructivist view of learning into Fiji schools. Clearly, as mentioned, this has not been properly researched. Furthermore, teachers at all levels would require considerable in-service training in this approach. However, even if these issues were to be addressed, the education system in Fiji, as it stands, would not readily accommodate such a change.

Resistance to changes in pedagogy is often very high amongst both Indian and Fijian teachers in Fiji. Sometimes this is for purely pragmatic reasons. For example, it is difficult to implement collaborative group learning given very large class sizes. More often though the teachers are reluctant to adopt innovative teaching strategies as the tried and trusted methods of exposition and 'drilling' of students prove to be effective in an education system with such a strong examination culture. This, combined with the highly prescriptive Basic Science curriculum which operates from Year 7 to Year 10, acts to stifle innovative teaching. As one student at the Lautoka Teachers' College put it:

> What the (primary) teachers do if they get exam classes, they just drill on the students...they teach us art and craft and PE here, even music...none of that is taught in the exam classes...I've seem how they do things are done, there is nothing of that, just the exam subjects, they just drill you and drill you, the children get no moral enrichment, they don't get much in music and they don't have their artistic development...what they do have is just cramming and rote learning. There are so many (national) exams to do, five of them, that's too much.

As long as the current, extremely competitive, examination system exists in Fiji, it is unlikely that practices in teaching will change. Even teachers exposed to innovative strategies which they found useful are likely to revert to the practices which the present system demands as they come under pressure from principals and parents concerned with examination results. Sadly, the current system deprives many students of the type of teaching which not only helps make science interesting, but also provides them with experiences which lead to meaningful learning. This is particularly unfortunate because, as research by Twoli and Power (1989) indicates, the school and teacher characteristics play a more significant role in shaping science attitudes and achievement in developing countries than in developed countries where home background is a more significant factor.

Any changes in the present system of assessment in Fiji are likely to be evolutionary rather than revolutionary. Thus perhaps, as mentioned in recommendation four, encouraging pre-service teachers to think more deeply about assessment and how this impacts the entire education system in Fiji may be one possible way to start a process of change. Certainly, given a change in the assessment system in Fiji, there is much evidence from this present study to suggest that there are teaching strategies available to improve the learning of science amongst both Fijians and Indians.

References

Abrams, R. (Ed.). (in press). *Proceedings of the fourth international seminar: From misconceptions to constructed understanding.* Ithaca, NY: Cornell University.

Adamczyk, P., & Wilson, P. (1996). Using concept maps with trainee physics teachers. *Physics Education, 31*(4), 374-381.

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27,* 1-52.

Albanese, A., & Vicentini, M. (1997). Why do we believe that an atom is colourless? Reflections about the teaching of the particle model. *Science & Education, 6,* 251-261.

Anderson, C. (1991). Policy implications of research on science teaching and teachers' knowledge. In M. M. Kennedy (Ed.), *Teaching academic subjects to diverse learners* (pp. 5-31). New York: Teachers College Press.

Anderson, C., & Smith, E. (1983). *Teacher behaviour associated with conceptual learning.* Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Anderson, C., & Smith, E. (1985). Teaching science. In V. Koehler (Ed.), *The educator's handbook: A research perspective* (pp. 80-111). New York: Longman.

Andersson, B. (1990). Pupils' conceptions of matter and its transformation. *Studies in Science Education, 18,* 53-85.

Andersson, B., & Karrquist, C. (1983). How Swedish pupils, aged 12-15 years, understand light and its properties. *European Journal of Science Education, 5*(4), 387-402.

Apelis, E. T. (1980). Anthropology and education in Papua New Guinea. *Papua New Guinea Journal of Education, 16*(1), 1-11.

Apelman, M. (1984). Critical barriers to the understanding of elementary science: Learning about light and colour. In C. Anderson (Ed.), *Observing science classrooms: Observing science perspectives from research and practice* (pp 3-37). AETS yearbook. Columbus, OH: ERIC/SMEAC.

Appleton, K. (1995). Student teachers' confidence to teach science: Is more science knowledge necessary to improve self-confidence? *International Journal of Science Education, 17*(3), 357-369.

Austen, L. (1995). (personal communication).

Ausubel, D. P. (1968). *Educational Psychology: A cognitive view.* New York NY: Holt, Rinehart & Winston.

Baba, T. L. (1982). Some researchable problems in Fijian education. In R. A. C. Stewart (Ed.), *Human development in the South Pacific: A book of readings* (pp 125-133). Suva, Fiji: The University of the South Pacific.

Bajracharya, J., & Brouwer, W. (1997). A narrative approach to science teaching in Nepal. *International Journal of Science Education, 19*(4), 429-446.

Baker, D., & Taylor, P. C. S. (1995). The effect of culture on the learning of science in non-Western countries: The results of an integrated research review. *International Journal of Science Education, 17*(6), 695-704.

Bar, V. (1990). *The development of the concept of evaporation.* Jerusalem: The Hebrew University Press.

Bar, V., & Travis, A. S. (1991). Children's views concerning phase change. *Journal of Research in Science Teaching, 28*(4), 363-382.

Basow, S. A. (1980). *Cross-cultural patterns in achievement motivation - ethnic group and sex comparisons in Fiji.* Unpublished paper, Lafayette College, Easton, Pennsylvania, USA.

Bell, B. F. (1993). *Children's science, constructivism and learning in science.* Victoria: Deakin University Press.

Bell, B. F., & Osborne, R. J. (1981*). Interviewing children-a checklist for the I.A.I. interviewer. Working Paper No. 45, Learning in science project.* Waikato NZ: University of Waikato.

Bendall, S., Goldberg, F., & Galili, I. (1993). Prospective elementary teachers' prior knowledge about light. *Journal of Research in Science Teaching, 30*(9), 1169-1187.

Bennett, M. J. (1970). Reasoning test response in urban and rural Fijian and Indian groups in Fiji. *Australian Psychologist, 5*(3), 260-266.

Bennett, N., & Turner-Blisset, R. (1993). Case studies in learning to teach. In N. Bennett & C. Carré (Eds.), *Learning to teach* (pp.165-191). London: Routledge.

Bennett, N., Wragg, E. C., Carré C., & Carter, D. S. G. (1992). A longitudinal study of primary teachers' perceived competence in, and concerns about, National Curriculum implementation. *Research Papers in Education, 7*(1), 53-78.

Bereiter, C. (1994). Constructivism, socioculturalism, and Popper's world 3. *Educational Researcher, 23*(7), 21-23.

Best, J. W., & Kahn, J. V. (1989). *Research in education.* Englewood, NJ: Prentice-Hall.

Blumenfeld, P. C., Marx, R. W., Soloway, E., & Krajcik, J. (1996). Learning with peers: From small group co-operation to collaborative communities. *Educational Researcher, 25*(8), 37-40.

Boyes, E., & Stanisstreet, M. (1991). Development of pupils' ideas about seeing and hearing-the path of light and sound. *Research in Science and Technological Education, 9*(2), 223-244.

Brook, A., Briggs, H., & Driver, R. (1984). *Aspects of secondary students' understanding of the particulate nature of matter. Children's learning in science project.*: Leeds, UK: University of Leeds.

Brook, A., & Driver, R.(1989). *Progression in science: The development of pupils' understanding of physical characteristics of air across the age range 5-16 years. Children's learning in science project.*: Leeds, UK: University of Leeds.

Brophy, J. (1991). Conclusion. In J. Brophy (Ed.), *Advances in research on teaching* (pp. 345-335). Greenwich, CT: J.A.I. Press.

Brophy, J., & Good, T. (1986). Teacher behaviour and student achievement. In M. Whitrock (Ed.), *Research on Teaching* 3rd ed (pp. 328-375). New York NY: Macmillan.

Brown, D. E. (1992). Using examples and analogies to remediate misconceptions in physics; factors influencing conceptual change. *Journal of Research in Science Teaching, 29,* 17-34.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237-261.

Brown, D. E., & Clement, J. (1992). Classroom teaching experiments in mechanics. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 380-398). Proceedings of an International Workshop: Keil, Germany, IPN.

Bruning, J. L., & Kintz, B. L. (1968). *Computational handbook of statistics*. Illinois: Scott, Foresman and Company.

Burgess, R. G. (Ed.). (1984). *The research process in educational settings: Ten case studies.* Lewes, UK: The Falmer Press.

Burns, R. B. (1994). *Introduction to research methods in education.* Cheshire: Longman.

Burrell, G., & Morgan, G. (1979). *Sociological paradigms and organisational analysis*. London: Heinemann.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research.* Chicago: Rand McNally.

Carmichael, P., Driver, R., Holding, B., Phillips, I., Twigger, D., & Watts, M. (1990). *Research on students' conceptions in science: A bibliography. Children's learning in science project.*: Leeds, UK: University of Leeds.

Carré, C. (1993). Performance in subject-matter knowledge in science. In N. Bennett & C. Carré (Eds.), *Learning to teach* (pp. 18-36). London: Routledge.

Carré, C., & Carter, D.S.G. (1990). Primary teachers' self-perceptions concerning implementation of the national curriculum in science in the UK. *International Journal of Science Education, 12*(4), 327-341.

Champagne, A. B., Gunstone, R. F., & Klopfer, L. E. (1985a). Effecting changes in cognitive structures among physics students. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 163-186). Orlando FL: Academic Press.

Champagne, A. B., Gunstone, R. F., & Klopfer, L. E. (1985b). Instructional consequences of students' knowledge about physical phenomena. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 61-90). Orlando FL: Academic Press.

Chandra, S. (1975a). Some patterns of response on the Queensland test. *Australian Psychologist, 10,* 185-192.

Chandra, S. (1975b). Cognitive development of Indians and Fijians. In T. Berry & W. Lonner (Eds.), *Applied cross-cultural psychology* (pp. 248-253). Amsterdam: Swets and Zetlinger.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121-152.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*(1), 1-49.

Christensen, C. (1995, August). *Prac reports: An alternative approach.* Paper presented at the Australian Science Teachers' Conference, Brisbane, Australia.

Cizek, G. J. (1995). Crunchy granola and the hegemony of the narrative. *Educational Researcher, 24*(2), 26-28.

Claxton, G. (1984). *Live and learn.* London: Harper and Row.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*(1), 66-71.

Clement, J. (1987). Overcoming students' misconceptions in physics: The role of anchoring intuitions and analogical validity. In J. Novak (Ed.), *Proceedings of the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 84-97). Ithaca, NY: Cornell University.

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding 'anchoring conceptions' for grounding instruction on students' intuitions. *International Journal of Science Education, 11,* 554-565.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23*(7), 13-20.

Cobern, W. W. (1991). *Worldview theory and science education research.* Monographs of the National Association for Research in Science Teaching, 3. Manhattan, Kansas State University.

Cobern, W. W. (1993a). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 51-69). Washington, DC: American Association for the Advancement of Science Press.

Cobern, W. W. (1993b). College students' conceptualisation of nature: An interpretive world view analysis. *Journal of Research in Science Teaching, 30*(8), 935-951.

Cobern, W. W. (1996a). Constructivism and non-western science educational research. *International Journal of Science Education, 18*(3), 295-310.

Cobern, W. W. (1996b). Worldview theory and conceptual change in science education. *Science Education, 80*(5), 579-610.

Cohen, E. G. (1984). Talking and working together: Status, interaction and learning. In P. L. Peterson, L. R. Wilkinson, & M. Hallihan (Eds.), *The social context of instruction* (pp. 171-187). New York: Academic Press.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: teaching the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Cognition and instruction: Issues and agendas* (pp. 453-494). Hillsdale, NJ: Erlbaum.

Cook, A., Stir, J., & Russell, N. (1992). The Fiji Secondary Science Practical Optimisation Project. *Directions, 14*(1), 29-43.

Cook, A., & Taylor, N. (1994). Robust adaptive processes: The case for laboratory assistants in Fiji high schools. *Journal of Science and Mathematics Education in South East Asia, 17*(2), 7-15.

Cook, T. D. (1983). Quasi-experimentation: Its ontology, epistemology, and methodology. In G. Morgan (Ed.), *Beyond method: Strategies for social research* (pp. 74-94). London: Sage Publications.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field settings.* Boston: Houghton Mifflin Company.

Cronin-Jones, L. L. (1991). Science teacher beliefs and their influences on curriculum implementation-Two case studies. *Journal of Research in Science Teaching, 28*(3), 235-251.

Dart, F. E. (1971). Towards a scientific attitude in developing countries. *Papua New Guinea Journal of Education, 7*(2), 19-26.

Dasen, P. R. (1974). The influence of ecology, culture and European contact on cognitive development in Australian Aborigines. In J. W. Berry, & P. R. Dasen, (Eds.), *Culture and Cognition: Readings in Cross-cultural Psychology* (pp. 381-409). London: Methuen.

Department of Education and Science. (1978). *Primary education in England: A survey by HM inspectorate.* London: HMSO.

Dewey, J. (1916). *Democracy and education.* New York: Macmillan.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the 'cognitive conflict' strategy for conceptual change - some implications, difficulties and problems. *Science Education, 74*(5), 555-569.

Driver, R. (1981). Pupil's alternative frame works in science. *European Journal of Science Education, 3*(1), 93-101.

Driver, R. (1985). Beyond appearances: The conservation of matter under physical and chemical transformations. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.), *Children's ideas in science* (pp. 145-170). Milton Keynes, UK: Open University Press.

Driver, R. (1987). Promoting conceptual change in classroom settings: The experience of the Children's Learning in Science Project. In J. D. Novak (Ed.), *Proceedings from the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 97-107). Ithaca, NY: Cornell University.

Driver, R. (1988). A constructivist approach to curriculum development. In P. J. Fensham (Ed.), *Development and dilemmas in science education* (pp. 133-149). London: The Falmer Press.

Driver, R. (1989). The construction of scientific knowledge in school classrooms. In R. Millar (Ed.), *Doing science: Images of science in science education* (pp. 83-106). London: The Falmer Press.

Driver, R., Asoko, H., Leach, J., Mortimer, J., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: A constructivist view. *School Science Review, 67*(240), 443-456.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5,* 61-84.

Driver, R., Guesne, E., & Tiberghien, A. (1985). Children's ideas and the learning of science. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.), *Children's ideas in science* (pp. 1-10). Milton Keynes, UK: Open University Press.

Driver, R., Leach, J., Scott, P., & Wood-Robinson, C. (1994). Young people's understanding of science concepts: Implications of cross-age studies for curriculum planning. *Studies in Science Education, 24,* 75-100.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13,* 105-122.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education, 75*(6), 649-672.

Duit, R. (1994). Research on students' conceptions-developments and trends. In H. Pfundt & R. Duit (Eds.), *Bibliography: Students' alternative frameworks and science education (3rd ed.)* (pp. xxii-xlii). Kiel, Germany: University of Kiel.

Dunne, M., & Rennie, L. (1990). The influence of gender, ethnicity and rurality upon perceptions of science. *Research in Science Education, 20,* 57-65.

Dupin, J. J., & Joshua, S. (1989). Analogies and " modelling analogies" in teaching. Some examples in basic electricity. *Science Education, 73,* 207-224.

Duschl, R. A. (1983). The elementary level science methods course: A breeding ground of an apprehension toward science? A case study. *Journal of Research in Science Teaching, 20,* 745-754.

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education, 76*(6), 615-652.

Ebenezer, J. V., & Erickson, G. L. (1996). Chemistry students' conceptions of solubility: A phenomography. *Science Education, 80*(2), 181-201.

Elkana, Y. (1972). *The theory and practice of cross-cultural contacts in science: Questions and presuppositions.* Jerusalem: Hebrew University of Jerusalem.

Elkana, Y. (1981). A programmatic attempt at an anthropology of knowledge. In E. Mendelsohn & Y. Elkana (Eds.), *Science and cultures: Anthropological and historical studies of the sciences* (pp. 1-79). Dordrecht, The Netherlands: Reidel.

Elley, W., & Mangubhai, F. (1979). Research project on reading in Fiji. *Fiji English Teachers' Journal, 15,* 1-7.

Elley, W., & Thomson, J. (1978). *The English language skills of USP foundation students.* Unpublished report to the School of Education Board of Studies, University of the South Pacific.

Elley, W., & Thomson, J. (1979). *The English language skills of USP foundation students.* Unpublished report to the School of Education Board of Studies, University of the South Pacific.

Engel Clough, E., Driver, R., & Wood-Robinson, C. (1987). How do children's scientific ideas change over time? *Secondary Science Review, 69*(247), 255-267.

Erickson, G. L. (1979). Children's conceptions of heat and temperature. *Science Education 63*(2), 221-230.

Erickson, G. L. (1980). Children's viewpoints of heat: A second look. *Science Education 64*(3), 323- 336.

Europa Publications. (1994). *Europa world year book.* (Vol. 1). London, UK: Europa Publications.

Feher, E., & Rice, K. (1987). A comparison of teacher-student conceptions in optics. In J. Novak (Ed.), *Proceedings of the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 108-118). Ithaca, NY: Cornell University.

Fellows, N. J. (1994, April). *Dynamics of conceptual change in small group science interactions.* Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Fensham, P. (1988). Familiar but different: Some dilemmas and new directions in science education. In P. Fensham (Ed.), *Developments and dilemmas in science education* (pp. 1-26). London: The Falmer Press,

Fiji Ministry of Education. (1981). *Basic Science 1. Teacher's Handbook.* Suva, Fiji: Fiji Ministry of Education.

Fiji Ministry of Education. (1982). *Basic Science 1. Pupil's Workbook.* Suva, Fiji: Fiji Ministry of Education.

Fiji Ministry of Education. (1982). *Basic Science 3 Pupil's Book.* Suva, Fiji: Fiji Ministry of Education.

Fiji Ministry of Education. (1984). *Basic Science 2. Unit 3. Pressure. Teacher's Handbook.* Suva, Fiji: Fiji Ministry of Education.

Fiji Ministry of Education. (1992). *Lautoka Teachers' College Prospectus.* Suva, Fiji: Fiji Ministry of Education.

Fiji Ministry of Education. (1996). (personal communication).

Filstead, W. J. (1979). Qualitative methods-a needed perspective in evaluation research. In T. D. Cook & C. S. R. Rerchardt (Eds.), *Qualitative and quantitative methods in evaluation research* (pp. 33-48). London: Sage Publications.

Filstead, W. J. (1982). Qualitative and quantitative information in health policy decision making. In E. R. House & Associates (Eds.), *Evaluation studies review annual: (Vol. 7),* (pp. 704-17). Beverley Hills, CA: Sage Publications.

Franz, J. R., & Enochs, L. G. (1982). Elementary school science: State certification requirements in science and their implications. *Science Education, 66*, 287-292.

Gabel, D. L. (1993). Use of the particle nature of matter in developing conceptual understanding. *Journal of Chemistry Education, 70*(3), 193-194.

Galili, I., Bendall, S., & Goldberg, F. (1993). The effect of prior knowledge and instruction on understanding image formation. *Journal of Research in Science Teaching, 30*(3), 271-301.

Garnett, P. J., & Tobin, K. (1988). Teaching for understanding: Exemplary practice in high school chemistry. *Journal Research in Science Teaching, 26*(1), 1-14.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum.

George, C. (1991). School science and ethnoscience. *Journal of Science and Mathematics Education in South East Asia, 14*(2), 27-36.

George, J. (1989). Sources of students' misconceptions in science, the cultural context. *Journal of Science and Mathematics Education in South East Asia, 12*(2), 13-20.

George, J., & Glasgow, J. (1989). Some cultural implications of teaching towards common syllabi in science: A case study from the Caribbean. *School Science Review, 71*(254), 115-123.

Gilbert, J. K., Osborne, R. J., & Fensham, P. (1982). Children's science and its consequences for teaching. *Science Education, 66*(4), 623-633.

Gilbert, J. K., & Swift, D. J. (1985). Towards a Lakatosian analysis of the Piagetian and alternative conception research programs. *Science Education, 69*(5), 681-696.

Gilbert, J. K., & Watts, D. M. (1983). Conceptions, misconceptions and alternative conceptions: Changing perspectives in science education. *Studies in Science Education, 10*, 61-98.

Gilbert, J. K., Watts, D. M., & Osborne, R. J. (1985). Eliciting student views using an interview-about-instances technique. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 2-27). New York: Academic Press.

Gillies, R. M., & Ashman, A. F. (1994). Cooperative learning in schools. *Queensland Teachers' Journal, 12*(1), 23- 25.

Ginns, I. S., & Foster, W. J. (1983). Preservice elementary teacher attitudes to science and science teaching. *Science Education, 67*(2), 277-282.

Ginns, I. S., & Watters, J. J. (1995). An analysis of understandings of preservice elementary teacher education students. *Journal of Research in Science Teaching, 32*(2), 205-222.

Ginns, I. S., Watters, J. J., Tulip, D., & Lucas, K. B. (1995) Changes in teachers' sense of efficacy in teaching science: A study of Australian preservice elementary school teachers. *School Science and Mathematics, 95*(8), 394-400.

Glynn, S. M. (1991). Explaining science concepts: A teaching-with-analogies model. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 219-240). Hillside, NJ: Erlbraum.

Glynn, S. M., Britton, B. K., Semrud-Clikeman, M., & Muth, K. D. (1989). Analogical reasoning and problem solving in textbooks. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity: Assessment, theory and research* (pp. 383-398). New York: Plenum.

Goodwin, L. D., & Goodwin, W. L. (1984). Qualitative vs quantitative research or qualitative and quantitative research? *Nursing Research, 33*(6), 378-380.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Towards a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274.

Greenfield, T. A. (1996). Gender, ethnicity, science achievement and attitudes. *Journal of Research in Science Teaching, 33*(8), 901-933.

Gronlund, N. E., & Linn, R. L. (1990). *Measurement and evaluation in teaching.* New York: Macmillan Publishing Company.

Grossman, P. L., Wilson, S. M., & Shulman, L. S. (1989). Teachers of substance: Subject matter knowledge for teaching. In M. C. Reynolds (Ed.), *Knowledge base for the beginning teacher* (pp. 23-37). New York: Pergamon.

Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.), *Children's ideas in science* (pp. 10-33). Milton Keynes, UK: Open University Press.

Gunstone, R. F., Champagne, A. B., & Klopfer, L. E. (1981) Instruction for understanding: A case study. *Australian Science Teachers' Journal, 27*(3), 27-32.

Gunstone, R. F., & Northfield, J. (1994). Metacognition and learning to teach. *International Journal of Science Education, 16*(5), 523-537.

Guzzetti, B. J., Snyder, T. E., Glass, G. E., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28*(2), 117-155.

Hacker, R. G., & Rowe, M. J. (1985). A study of teaching and learning processes in integrated science classrooms. *European Journal of Science Education, 7,* 173-183.

Haladyna, T., Olsen, R., & Shaughnessy, J. (1983). Correlates of attitude towards science. *Journal of Research in Science Teaching, 20*(4), 311-324.

Harlen, W. (1985). *Teaching and learning primary science.* London: Harper and Row.

Harlen, W., Black, P., & Johnson, S. (1981). *Science in Schools Age 11; Report 1,* London: HMSO for the Assessment Performance Unit.

Harlen, W., & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. *International Journal of Science Education, 19*(1), 93-105.

Haslam, F., & Treagust, D. F. (1987). Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education, 21*(3), 203-211.

Hatano, G., & Inagaki, K. (1987). A theory of motivation for comprehension and its application to mathematics education. In T. A. Romberg & D. M. Steward (Eds.), *The monitoring of school mathematics: Background papers, (Vol. 2). Implications from psychology, outcomes of instruction* (pp. 26-66). Madison: Wisconsin Centre for Educational Research.

Helgeson, S., Blosser, P., & Howe, R. (1977). *The status of pre-college science , math and social science education, 1955-1977, (Vol. 1). Science Education.* Washington, DC: US Government Printing Office.

Helm, H. (1978). Misconceptions about physical concepts among South African pupils studying physical science. *South African Journal of Science, 74,* 285-290.

Helm, H. (1980). Misconceptions in physics amongst South African students. *Physics Education, 15,* 92-97.

Helm, H., & Novak, J. D. (Eds.). (1983). *Proceedings of the international seminar in science and mathematics.* Ithaca, NY: Cornell University.

Henry, N. B. (Ed.). (1947). *Science education in American schools.* The forty-sixth yearbook of the National Society for the study of education. Chicago: The University of Chicago Press.

Hewson, M. G. (1982). *Students' existing knowledge as a factor influencing the acquisition of scientific knowledge.* Unpublished PhD thesis. University of the Witwatersrand, South Africa.

Hewson, M. G. (1988). The ecological context of knowledge: Implications for learning science in developing countries. *Journal of Curriculum Studies, 20*(4), 317-326.

Hewson, M. G., & Hamlyn, D. (1984). The influence of the intellectual environment on conceptions of heat. *European Journal of Science Education, 6*(3), 245-262.

Hewson, M. G., & Hewson, P. W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 20*(8), 731-743.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education*, *3*(4), 383-396.

Hewson, P. W. (1983, April). *Microcomputers and conceptual change: The use of a microcomputer program to diagnose and remediate alternative conception of speed.* Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Hewson, P. W., & Hewson, M. G. (1987). Science teacher conceptions of teaching: Implications for teacher training. *International Journal of Science Education, 9,* 425-440.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education, 11,* 541-553.

Holding, B. (1987). *Investigation of school children's understanding of the process of dissolving with special reference to the conservation of matter and the development of atomic ideas.* Unpublished PhD thesis, University of Leeds, UK.

Hollon, R., & Anderson, G. (1986, April). *Teachers' understanding of students scientific thinking: Its influence on planning and teaching.* Paper presented at the annual meeting of the National Association for Research in Science, San Francisco, CA.

Hollon, R., & Anderson, C. (1987, April). *Teachers' beliefs about students' learning processes in science: Self-reinforcing belief systems.* Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

Ingle, R. B., & Turner, A. D. (1981). Science curricula as cultural misfits. *European Journal of Science Education, 3,* 357-371.

Ivowi, U. M. O. (1984). Misconceptions in physics amongst Nigerian secondary school students. *Physics Education, 19,* 279-285.

Jeans, D. N. (1974). Changing formulations of the man-environment relationship in Anglo-American geography. *Journal of Geography, 73*(3), 36-40.

Jegede, O. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education. *Studies in Science Education, 25,* 97-137.

Jegede, O. (1997). School science and the development of scientific culture: A review of contemporary science in Africa. *International Journal of Science Education, 19*(1), 1-20.

Jegede, O, Alaiyemola, F., & Okebukola, P. A. (1990). The effect of concept mapping on students' anxiety and achievement in biology. *Journal of Research in Science Teaching, 27*(10), 951-960.

Jegede, O, Lagoke, B. A., & Oyebanji, P. R. (1995). The use of environmental analogs to enhance biological learning among senior secondary school students. Unpublished manuscript.

Jegede, O., & Okebukola, P. A. (1988). An educology of socio-cultural factors in science classrooms. *International Journal of Educology, 2*(2), 93-107.

Jegede, O., & Okebukola, P. A. (1989). Some socio-cultural factors militating against the drift towards science and technology in secondary schools. *Research in Science and Technology Education, 7*(8), 141-151.

Jegede, O., & Okebukola, P. A. (1991a). The relationship between African traditional cosmology and students' acquisition of a science process skill. *International Journal of Science Education, 13*(1), 37-47.

Jegede, O., & Okebukola, P. A. (1991b).The effect of instruction on socio-cultural beliefs hindering the learning of science. *Journal of Research in Science Teaching, 28*(3), 275-285.

Johnson, D. W., & Johnson, R. T. (1990). Cooperative learning and achievement. In S. Sharan (Ed.), *Cooperative learning: Theory and research* (pp. 23-37). New York: Praeger.

Johnson, D. W., & Johnson, R. T. (1995). Cooperative learning. In J. H. Block, S. T. Everson, & T. R. Guskey (Eds.), *School improvement programs: A handbook for educational leaders* (pp. 25-56). New York: Scholastic.

Johnson, D. W., Johnson, R. T., & Holubec, E. (1993). *Cooperation in the classroom* (5th ed.). Edina, MN: Interaction Book Company.

Jung, W. (1986). Alltagsvorstellungen und das Lernen von Physik und Chemie. *Naturwissenschaften im Unterricht - Physik/Chemie, 34*(13), 2-6.

Kahn, M. (1990). Paradigm lost: The importance of practical work in school science from a developing country perspective. *Studies in Science Education, 18*, 127-136.

Karmiloff-Smith, A. (1988). The child is a theoretician, not an individualist. *Mind and Language, 3*(3), 183-195.

Kei, L. K., & Mee, L. S. (1991). Concept mapping strategy for meaningful learning. *Journal of Science and Mathematics Education in South East Asia, 14*(2), 37-45.

Kelly, G. A. (1955). *The psychology of personal constructs.* New York: W. W. Norton.

Kempa, R. F., & Ayob, A. (1995). Learning from group work in science. *International Journal of Science Education, 17*(6), 743-754.

Kirkwood, V., Bearlin, M., & Hardy, T. (1989). New approaches to inservice education in science and technology of primary and early childhood teachers. *Research in Science Education, 19,* 174-186.

Kishor, N. (1982). The effect of self-esteem and locus of control in career decision-making of adolescents in Fiji. In R. A. C. Stewart (Ed.), *Human development in the South Pacific: A book of readings* (pp. 317-331). Suva, Fiji: The University of the South Pacific.

Klausmeier, H. J., Ghatala, E. S., & Frayer, D. A. (1974). *Conceptual learning and development - a cognitive view.* New York: Academic Press.

Kruger, C. (1990). Some primary school teachers' ideas about energy. *Physics Education, 25*, 86-91.

Kruger, C., Palacio, D., & Summers, M. (1990). A survey of primary school teachers' conceptions of force and motion. *Educational Research, 32*, 83-95.

Kruger, C., Palacio, D., & Summers, M. (1991). *Understanding forces.* Pack 1 of the series Understanding Science Concepts: Teacher Education Materials for Primary School Science. Oxford, UK: University of Oxford.

Kruger, C., Palacio, D., & Summers, M. (1992). Surveys of English primary school teachers' conceptions of force, energy and materials. *Science Education, 76*(4), 339-351.

Kruger, C., & Summers, M. (1988). Primary school teachers' understanding of science. *Journal of Education for Teaching, 14*(3), 259-265.

Kruger, C., & Summers, M. (1989). Some primary teachers' understanding of changes in materials. *School Science Review, 71*(255), 17-27.

Kruger, C., Summers, M., & Palacio, D. (1990a). An investigation of some English primary school teachers' understanding of the concept of force and gravity. *British Educational Research Journal, 16*(4), 383-397.

Kruger, C., Summers, M., & Palacio, D. (1990b). INSET for primary science in the National Curriculum in England and Wales: Are the real needs of teachers perceived? *Journal of Education for Teaching, 16*(2), 133-146.

Krugly-Smolska, E. (1996). Scientific culture, multiculturalism and the science classroom. *Science & Education, 5,* 21-29.

de Laat, J., & Watters, J. J. (1995, July). *Science teaching self efficacy in a primary school: A case study*. Paper presented at the annual meeting of the Australasian Science Education Research Association, La Trobe University, Bendigo, Victoria, Australia.

Lake, D. C. (1993). The cultural background of teachers' college entry students and the implications for science teaching. *Papua New Guinea Journal of Education, 29*(1), 33-46.

Lawrenz, F. (1986). Misconceptions of physical science concepts among elementary school teachers. *School Science and Mathematics, 86*, 654-660.

Lazarowitz, R., Baird, J H., & Allman, V. (1985). Reasons why elementary and secondary students in Utah do and do not like science. *School Science and Mathematics, 85*, 663-672.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1995). Children's ideas about ecology 1: Theoretical background, design and methodology. *International Journal of Science Education, 17*(6), 721-732.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of research. *Journal of Research in Science Teaching, 29*(4), 331-359.

Lee, C. (1983). *The ostrich position: Sex, schooling and mystification.* London, UK: Writers and Readers Publishing Co-operative Society.

Lee, O. (1995). Subject matter knowledge, classroom management, and instructional practices in middle school science classrooms. *Journal of Research in Science Teaching, 32*(4), 423-440.

Lee, O., Eichinger, D. C., Anderson, C. W., Berkheimer, G. D., & Blakeslee, T. D. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching, 30*(3), 249-270.

Lenton, G., & McNeil, J. (1991a). *Prevalence Phase-Results from the biology questionnaire. Working Paper No. 13.* PSTS Project. Oxford, UK: Oxford University Department of Educational Studies/Westminster College.

Lenton, G., & McNeil, J. (1991b). *Selected findings from the biology interviews and questionnaire. Working Paper No. 14,* PSTS Project. Oxford, UK: Oxford University Department of Educational Studies/Westminster College.

Lewin, K. (1990a). International perspectives on the development of science education: Food for thought. *Studies in Science Education, 18,* 1-23.

Lewin, K. (1990b). Research design in retrospect: Malaysia and Sri Lanka. In G. Vulliamy, K. Lewin, & D. Stephens (Eds.), *Doing educational research in developing countries* (pp. 46-68). London: The Falmer Press.

Lewin, K. (1993). Planning policy on science in developing countries. *International Journal of Science Education, 15*(1), 1-15.

Lillis, K. M. (1982). Issues of relevance in Kenyan mathematics and science curricula. *International Journal of Educational Development, 1*(3), 1-12.

Linke, R. D., & Venz, M. I. (1978). Misconceptions in physical science among non-science background students. *Research in Science Education, 8,* 183-193.

Linke, R. D., & Venz, M. I. (1979). Misconceptions in physical science among non-science background students: II. *Research in Science Education, 9,* 103-109.

Linn, M., & Burbules, N. (1993). Construction of knowledge and group learning. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp.91-119). Washington: AAAS Press.

Lucas, K. B., & Dooley, J. H. (1982). Student teacher attitudes towards science and science teaching. *Journal of Research in Science Teaching, 19*(9), 805-809.

Lynch, P. P. (1996a). Students' alternative frameworks: Linguistic and cultural interpretations based on a study of a western-tribal continuum. *International Journal of Science Education, 18* (3), 321-332.

Lynch, P. P. (1996b). Students' alternative frameworks for the nature of matter: A cross-cultural study of linguistic and cultural interpretations. *International Journal of Science Education, 18* (6), 743-752.

Lynch, P. P., & Jones, B. L. (1995). Students' alternative frameworks: A linguistic and cultural interpretation. *International Journal of Science Education, 17*(1), 107-118.

Macdonald, M. A., & Rogan, J. M. (1981). The science education project in the Ciskei. *South African Journal of Science, 77,* 353-355.

Macpherson, C. M., & Taylor, N. (1994). The national trial of the Standardised Test of Achievement in Science for Fiji: A comparison of sub-group performance within the sample population. *Journal of Science and Mathematics Education in South East Asia, 17*(1), 8-13.

Maddock, M. N. (1982). Attitudes to natural phenomena and traditional religion. *Papua New Guinea Journal of Education, 18*(2), 105-130.

Mali, G. B., & Howe, A. (1979). Development of earth and gravity concepts among Nepali children, *Science Education, 63*(5), 685-691.

Manning, P., Esler, W., & Baird, J. R. (1981). How much elementary science is really being taught? *Science and Children, 19*(8), 40-41.

Mant, J., & Summers, M. (1993). Some primary school teachers' understanding of the Earth's place in the universe. *Research Papers in Education, 8*(1), 101-129.

Markle, S. M., & Tiemann, P. W. (1970). "Behavioural" analysis of "cognitive" content. *Educational Technology, 10*(1), 41-45.

Mason, H. I. (1983). Report on the field trial of a kit of simple inexpensive science equipment. *Directions, 10,* 1-7.

Mason, S. A. (1993). Employing quantitative and qualitative methods in one study. *British Journal of Nursing, 2*(17), 869-872.

Matthews, C. E., & Smith, W. S. (1994). Native American related materials in elementary science instruction. *Journal of Research in Science Teaching, 31*(4), 363-380.

Matthews, M. (1993). Constructivism and science education: Some epistemological questions. *Journal of Science Education and Technology, 2*(1), 359-369.

Mechling, K. (1983). Taking charge: How principals can improve school science programs. *Principal, 62*(3), 16-21.

Miles, B. M., & Huberman, A. M. (1984). Drawing valid meaning from qualitative data: Towards a shared craft. *Educational Researcher, 13*(15), 20-30.

Millar, R. (1988). Teaching physics to non-specialists: The in-service training of science teachers. *Journal of Education for Teaching, 14*(1), 39-53.

Millar, R. (1989). Constructive criticisms. *International Journal of Science Education, 11,* 587-596.

Mitchell, I., & Gunstone, R. (1984). Some student conceptions brought to the study of stoichiometry. *Research in Science Education, 14,* 78-88.

Morrison, K. (1989). Training teachers for primary schools: The question of subject study. *Journal of Education for Teaching, 15*(2), 97-111.

Muralidhar, S. (1989). *An exploratory study of a science curriculum in action: Basic Science in Fiji.* Unpublished PhD thesis, Monash University, Melbourne, Australia.

Murfin, B. (1994). African science, African and African-American scientists and the school science curriculum. *School Science and Mathematics, 94*(2), 96-103.

McClelland, J. A. G. (1982). Ausubel's theory of learning and its application to introductory science. Part II. *School Science Review, 69*(247), 255-267.

McDiarmid, G. W., Ball, D. L., & Anderson, C. W. (1989). Why staying one step ahead doesn't really work: Subject specific pedagogy. In M. C. Reynolds (Ed.), *Knowledge base for the beginning teacher* (pp. 193-207). New York: Pergamon.

McKinley, E. (1996). Towards an indigenous science curriculum. *Research in Science Education, 26*(2), 155-167.

Nabobo, U., & Teasdale, J. (1994). Teacher education for cultural identity in Fiji. *Directions, 16*(2), 3-13.

Neale, D. (1987, April). *Primary teachers' current practices and needed expertise in science lessons.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington, DC.

Niaz, M. (1997). Can we integrate qualitative and quantitative research in science education? *Science and Education, 6,* 291-300.

Niedderer, H. (1987). A teaching strategy based on students' alternative frameworks - theoretical conceptions and examples. *Proceedings from the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 360-367). Ithaca, NY: Cornell University.

Ninnes, P. M., (1991). *Culture and learning in Western Province, Solomon Islands.* Unpublished MA Thesis, Flinders University, South Australia.

Noce, G., Torosantucci, G., & Vicentini, M. (1988). The floating of objects on the moon: Prediction from a theory or experimental fact? *International Journal of Science Education, 10*(1), 61-70.

Noh, T., & Scharmann, L. C. (1997). Instructional influence of a molecular-level pictorial presentation of matter on students' conceptions and problem-solving ability. *Journal of Research in Science Teaching, 34*(2), 199-217.

Novak, J. D. (Ed.). (1987). *Proceedings from the second international seminar: Misconceptions and educational strategies in science and mathematics.* Ithaca, NY: Cornell University.

Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching, 27*(10), 937-947.

Novak, J. D. (Ed.). (1993). *Proceedings of the third international seminar: Misconceptions and educational strategies in science and mathematics*. Ithaca, NY: Cornell University.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn.* New York: Cambridge University Press.

Novick, S., & Nussbaum, J. (1978). Junior high school pupils' understanding of the particulate nature of matter: An interview study. *Science Education, 62*(3), 273-281.

Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education, 65*(2), 187-196.

Nussbaum, J. (1985). The particulate nature of matter in the gaseous phase. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.), *Children's ideas in science* (pp. 124-145). Milton Keynes, UK: Open University Press.

Nussbaum, J. (1989). Classroom conceptual change: Philosophical perspectives. *International Journal of Science Education, 11,* 530-540.

Nussbaum, J., & Novick, S. (1982a). Alternative frameworks conceptual conflict and accommodation: Toward a principled teaching strategy. *Instructional Science, 11,* 183-200.

Nussbaum, J., & Novick, S. (1982b). *A study of conceptual change in the classroom.* Paper presented at the annual meeting of the National Association of Research in Science Teaching, Lake Geneva, USA.

Nussbaum, J., & Sharoni-Dagan N. (1983). Changes in second grade children's preconceptions about the earth as a cosmic body resulting from a series of audio-tutorial lessons. *Science Education, 67,* 99-114.

Ogawa, M. (1986). Towards a new rationale of science education in a non-Western society. *International Journal of Science Education, 8*(2), 113-119.

Ogawa, M. (1995). Science education in a multiscience perspective. *Science Education, 79*(5), 583-593.

Ogunniyi, M. (1988). Adapting western science to traditional African culture. *International Journal of Science Education, 10*(1), 1-9.

Ogunniyi, M., Jegede, O. J., Ogawa, M., Yandila, C. D., & Oladele, F. K. (1995). Nature of worldview presuppositions among science teachers in Botswana, Indonesia, Japan, Nigeria, and the Philippines. *Journal of Research in Science Teaching, 32*(8), 817-831.

Okebukola, P. A., & Jegede, O. J. (1988). Cognitive preference and learning mode as determinants of meaningful learning through concept mapping. *Science Education, 72*(4), 489-500.

Osborne, R., & Cosgrove, M. R. (1983). Children's conceptions of the of changes of state of water. *Journal of Research in Science Teaching, 20,* 825-838.

Osborne, R., Bell, B. F., & Gilbert, J. K. (1982). *Science teaching and children's view of the world.* Hamilton, NZ: S.E.R.U., University of Waikato.

Osborne, R., Biddulph, F., Freyberg, P., & Symington, D. (1982). *Confronting the problems of primary school science. Working Paper No. 110, Learning in science project,* Waikato, NZ: University of Waikato.

Osborne, R., & Freyberg, P. (1985). *Children's learning in science.* London: Heinemann.

Osborne, R. J., & Gilbert, J. K. (1979). Investigating student understanding of basic physics concepts using an interview-about-instances technique. *Research in Science Education, 9,* 85-93.

Osborne, R., & Gilbert, J. (1980a). A method for the investigation of concept understanding in science. *European Journal of Science Education, 2,* 311-21.

Osborne, R., & Gilbert, J. (1980b). A technique for exploring students' views of the world. *Physics Education 15*, 376-9.

Osborne, R., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education, 67*(4), 489-508.

O'Loughin, M. (1992). Rethinking science education: Beyond Piagetian constructivism towards a sociocultural model of learning and teaching. *Journal of Research in Science Teaching, 29*(8), 791-820.

Page, G. T., & Thomas, J. B. (1979). *The International Dictionary of Education.* London: Kogan Page.

Pendlington, S., Palacio, D., & Summers, M. (1993). *Understanding materials and why they change.* Pack 4 of the series Understanding Science Concepts: Teacher Education Materials for Primary School Science. Oxford, UK: University of Oxford.

Perkes, V. A. (1975). Relationships between a teacher's background and sensed adequacy to teach elementary science. *Journal of Research in Science Teaching, 12*(1), 85-88.

Pfundt, H., & Duit, R. (1994). *Bibliography: Students' alternative frameworks and science education* (3rd ed.). Kiel, Germany: University of Kiel.

Piaget, J. (1964). Development and learning. *Journal of Research in Science Teaching, 2,* 176-186.

Pintrich, P. R., Marx, R. W., & Boyle, A. R. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.

Pope, M., & Gilbert, J. (1983). Personal experience and the construction of knowledge. *Science Education, 67*(2), 193-203.

Popper, K. (1959). *The logic of scientific discovery.* London: Hutchinson.

Posner, G. J., & Gertzog, W. A. (1982). The clinical interview and the measurement of conceptual change. *Science Education, 66*(2), 195-209.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Primary School Teachers and Science Project (PSTS) (1993). *Working papers 1-17.* Oxford, UK: Oxford University Department of Educational Studies/Westminster College.

Qin, Z., Johnson, D. W., & Johnson, R. T. (1995). Cooperative versus competitive efforts and problem solving. *Review of Educational Research, 65*(2), 129-143.

Ramorogo, G. J., & Wood-Robinson, C. (1995). Batswana children's understanding of biological inheritance. *Journal of Biological Education, 29*(1), 60-72.

Reichardt, C. S., & Cook, T. D. (1979). Beyond qualitative versus quantitative methods. In T. D. Cook & C. S. Reichardt (Eds.), *Qualitative and quantitative methods in evaluation research* (pp. 7-33). Beverly Hills, CA: Sage Publications.

Renstrom, L., Andersson, B., & Marton, F. (1990). Students' conceptions of matter. *Journal of Educational Psychology, 82*(3), 555-569.

Rice, P. (1991). Concepts of health and illness in Thai children. *International Journal of Science Education, 13*(1), 555-127.

Rogers, R. S. (1974). *Sex education: Rationale and reaction.* Cambridge, UK: Cambridge University Press.

Rollnick, M. S. (1988). *Mother tongue instruction, intellectual environment and conceptual change strategies in the learning of science concepts in Swaziland.* Unpublished doctoral thesis, University of the Witwatersrand, Johannesburg.

Rollnick, M. S., & Rutherford, M. (1990). African primary school teachers-what ideas do they hold on air and air pressure? *International Journal of Science Education, 12*(1), 101-113.

Rollnick, M., & Rutherford, M. (1993). The use of a conceptual change model and mixed language strategy for remediating misconceptions on air pressure. *International Journal of Science Education, 15*(4), 363-381.

Rosenshine, B., & Meister, C. (1992). The use of scaffolds for teaching higher-level cognitive strategies. *Educational Leadership, 49*(7), 26-33.

Rossman, G. B., & Wilson, B. L. (1985). Words and numbers: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation Review, 9*(5), 627-643.

Roth, K. J. (1987, April). *Helping science teachers change: The critical role of teachers' knowledge about science and science learning.* Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

Roth, K. L. (1990). Developing meaningful conceptual understanding in science. In B. F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 139-175). Hillsdale, NJ: Lawrence Erlbaum Associates.

Roth, K., Anderson, C., & Smith, E. (1986). *Curriculum materials, teacher talk and student learning: Case studies in fifth grade science teaching.* (Research Series no. 17), Michigan: Michigan State University, The Institute of Research in Teaching.

Roth, W-M., & Roychoudhury, A. (1993). Using Vee and concept maps in collaborative setting: Elementary education majors construct meaning in physical science courses. *School Science and Mathematics, 93*(5), 237-244.

Rowell, J. A., & Dawson, C. J. (1985). Equilibration, conflict and instruction. *European Journal of Science Education, 4*(4), 331-344.

Rowell, J. A., Dawson, C. J., & Lyndon, H. (1990). Changing misconceptions: A challenge to science educators. *International Journal of Science Education, 12*(2), 167-175.

Rutherford, F. J. (1987). The character of elementary school science. *Science and Children, 24*(4), 8-11.

Russell, T., Bell, D., McGuigan, L., Qualter, A., Quinn, J., & Schilling, M. (1992). Teachers' conceptual understanding in science: Needs and possibilities in the primary phase. *Evaluation and Research in Education, 6*(2&3), 129-143.

Russell, T., Harlen, W., & Watt, D. (1989). Children's ideas about evaporation. *International Journal of Science Education, 11,* 566-576.

Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to. *International Journal of Science Education, 13,* 89-98.

Scott, P. H. (1992). Pathways in learning science: A case study of the development of one student's ideas relating to the structure of matter. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies.* Proceedings of an International Workshop (pp. 203-225). Kiel, Germany: IPN.

Scott, P. H., Asoko, H. M., & Driver, R. H. (1992). Teaching for conceptual change: A review of strategies. In R. Duit, F. Goldberg, & H. Niedderer (Eds.) *Research in physics learning: Theoretical issues and empirical studies.* Proceedings of an International Workshop (pp. 310-329). Kiel, Germany: IPN.

Shaeffer, S. (1986). Foreword. In B. Avalos, (Ed.), *Teaching children of the poor: An ethnographic study in Latin America* (pp. 5-6). Ottawa: International Development Research Centre.

Shahn, E. (1990a). Science as another culture/science as a part of culture. *American Behavioural Scientist, 34*(2), 210-222.

Shahn, E. (1990b). Foundations of science: A lab course for non-science majors. In D. E. Herget (Ed.), *The history and philosophy of science in science teaching: More proceedings of the first international conference* (pp. 310-352). Tallahasse, FL: Florida State University.

Shea, J. (1978). The study of cognitive developments in Papua New Guinea. *Papua New Guinea Journal of Education, 14,* 85-133.

Shepardson, D. P., Moje, E. B., & Kennard-McClelland, A. M. (1994). The impact of a science demonstration on children's understanding of air pressure. *Journal of Research in Science Teaching, 31*(3), 243-252.

Shotland, R. L., & Mark, M. M. (1987). Improving inferences from multiple methods. In M. M. Mark & R. L. Shotland (Eds.), *Multiple methods in program evaluation: New directions for program evaluation,* (No. 35). San Francisco: Jossey-Bass.

Shrigley, R. (1974). Correlation of science attitudes and science knowledge of preservice elementary teachers. *Science Education, 58*, 142-151.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 51,* 4-14.

Shulman, L. (1987). Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Shymansky, J. A., Woodworth, G., Norman, O., Dunkhase, J., Matthews, C., & Chin-Tang, L. (1993). A study of changes in middle school teachers' understanding of selected ideas in science as a function of an in-service program focusing on student preconceptions. *Journal of Research in Science Teaching, 30*(7), 737-755.

Sieben, G. (1987). Introducing concept mapping in the day to day science curriculum. In J. D. Novak (Ed.), *Proceedings from the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 436-446). Ithaca, NY: Cornell University.

Sigrah, A., Rilometo, J., & Albert, R. (1997). Science background of the elementary teachers on Majuro Atoll. *Pacific Island Focus, 3*(1), 67-78.

Skamp, K. (1989). General science knowledge and attitudes towards science and science teaching of preservice primary teachers: Implications for preservice science units. *Research in Science Education, 19,* 257-267.

Smith, D. C. (1987, April). *Primary teachers' substantive, syntactic and pedagogical content knowledge*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington DC.

Smith, D. C., & Neale, D. C. (1989). The construction of subject knowledge in primary science teaching. *Teaching and Teacher Education, 5*(1), 1-20.

Smith, E. L. (1991). A conceptual change model of learning. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 43-65). Hillside, NJ: Erlbraum.

Smith, E. L., & Anderson, C. W. (1987, April). *The effects of training and use of specially designed curriculum materials on conceptual change teaching and learning.* Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

Smith, E. L., & Lott, G. (1983). *Ways of going wrong in teaching for conceptual change.* Research Series No. 139. East Lansing: Michigan State University, Institute for Research on Teaching.

Smith, E. L., & Sendelbach, N. (1982). The program of plans and the activities of the classroom: The demands of activity-based science. In J. K. Olsen (Ed.), *Innovation in the science curriculum: Classroom knowledge and curriculum change* (pp. 72-106). London: Croom Helm.

Smith, J. K. (1983). Quantitative versus qualitative research: An attempt to clarify the issue. *Educational Researcher, 12*(3), 6-13.

Smith, R. G. (1997). "Before teaching I used to do a lot of reading." Preparing primary student teachers to teach science. *Research in Science Education, 27*(1), 141-154.

Smith, R. G., & Peacock, G. (1992). Tackling contradictions in teachers' understanding of gravity and air resistance. *Evaluation and Research in Education, 6*(2&3), 113-127.

Solomon, J. (1983). Learning about energy: How pupils think in two domains. *European Journal of Science Education, 5*(1), 49-59.

Solomon, J. (1987). Social influences on the construction of pupils' understanding of science. *Studies in Science Education, 14,* 63-82.

SPSS (1993) for Windows *(Release 6.0) [computer software].* Chicago: SPSS.

Stavy, R. (1988). Children's conception of gases. *International Journal of Science Education, 10*(5), 553-560.

Stavy, R. (1991). Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching, 28*(4), 305-313.

Stavy, R., & Stachel, D. (1985). Children's ideas about 'solid' and 'liquid'. *European Journal of Science Education, 7*(4), 407-421.

Stewart, J. (1980). Techniques for assessing and representing information in cognitive structure. *Science Education, 64*(2), 223-235.

Stewart, R. A. C. (1983). Fijian education - its specials demands. *Directions, 10,* 12-26.

Strike, K. A. (1987). Towards a coherent constructivism. In J. D. Novak (Ed.), *Proceedings from the second international seminar: Misconceptions and educational strategies in science and mathematics* (pp. 481-489). Ithaca, NY: Cornell University.

Strike, K. A., & Posner, G. J. (1982). Conceptual change and science teaching. *European Journal of Science Education, 4*(3), 231-240.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). Albany, NY: State University of New York Press.

Summers, M. (1992). Improving primary school teachers' understanding of science concepts - theory into practice. *International Journal of Science Education, 14*(1), 25-40.

Summers, M. (1994). Science in the primary school: The problem of teachers' curricular expertise. *The Curriculum Journal, 5*(2), 179-193.

Summers, M., & Kruger, C. (1992). Research into some English primary school teachers' understanding of the concept energy. *Evaluation and Research in Education, 6*(2&3), 95-111.

Summers, M., & Kruger, C. (1994). A longitudinal study of a constructivist approach to improving primary school teachers' subject matter knowledge in science. *Teaching and Teacher Education, 10*(5), 499-519.

Summers, M., & Mant, J. (1995). A survey of some primary school teachers' understanding of the Earth's place in the universe. *Educational Research 37*(1), 1-19.

Sutton, R. C. (1980). The learner's prior knowledge: A critical review of techniques for probing its organisation. *European Journal of Science Education, 2*(2), 107-120.

Swift, D. G. (1983). *Physics for rural development.* Chichester, UK: John Wiley.

Swift, D. G. (1987). School physics and rural technology. In J. Waddington (Ed.), *Education, Industry and Technology,* Oxford, UK: Pergamon.

Swift, D. G. (1992). Indigenous knowledge in the service of science and technology in developing countries. *Studies in Science Education, 20,*1-28.

Symington, D. (1974). Why so little primary science? *The Australian Science Teachers Journal, 20*(1), 57-62.

Symington, D. (1980). Primary school teachers' knowledge of science and its effect on choice between alternative verbal behaviours. *Research in Science Education, 10,* 69-76.

Tamir, P. (1971). An alternative approach to the construction of multiple choice test items. *Journal of Biological Education, 5,* 305-307.

Tan Boon Tee (1994). Preservice primary student teachers' conceptions of voltage and current in simple series and parallel circuits. *Journal of Science and Mathematics Education in South East Asia, 17*(1), 61-68.

Tasker, C. R. (1980). *Reconsidering the framework. Working paper No. 14, Learning in science project*. Waikato, NZ: University of Waikato.

Tasker, C. R. (1981). Children's views and classroom experiences. *Australian Science Teachers' Journal. 27*(3), 51-57.

Tavola, H. (1992). Race is not the only issue in education in Fiji. *Directions, 14*(2), 34-40.

Taylor, C. A. (1995). Cooperative learning in an African context. *International Journal of Educational Research, 23*(3), 239-253.

Taylor, N. (1991). The Fiji Junior Certificate Basic Science examination: Its implications for the teaching of science in Fiji. *Journal of Science and Mathematics Education in South East Asia, 14*(2), 73-78.

Taylor, N. (1993). Teaching science at the University of the South Pacific: Its special problems. *Journal of Indian Education, 18*(5), 18-23.

Taylor, N., & Macpherson, C. M. (1992a). Developing the Standardised Test of Achievement in Science for Fiji. *Journal of Science and Mathematics Education in South East Asia, 15*(1), 19-30.

Taylor, N., & Macpherson, C. M. (1992b). Primary science in Fiji: Some reflections on activity-based lessons. *Journal of Science and Mathematics Education in South East Asia, 15*(2), 40-45.

Taylor, N., & Macpherson, C. M. (1993). Environmental education in Fiji. *International Research in Geographic and Environmental Education, 2*(1), 3-10.

Taylor, N., & Macpherson, C. R. (1997). Traditional and religious beliefs and the teaching of science in Fiji. *New Zealand Journal of Educational Studies, 32*(2), 191-205.

Taylor, P. C. S. (1994, March). *Establishing a critical discourse on cultural myths that shape the social reality of the science classroom.* Paper presented at the annual meeting of the National Association for Research in Science Teaching. Anaheim, CA

Taylor, P. C. S., Fraser, B. J., & White, L. (1994, April). *CLES: An instrument for monitoring the development of constructivist learning environments.* Paper presented at the annual meeting of the American Educational Research Association Conference, New Orleans, LA.

Thijs, G. D., & van den Berg, E. (1995). Cultural factors in the origin and remediation of alternative conceptions in physics. *Science and Education, 4,* 317-347.

Tilgner, P. J. (1990). Avoiding science in the elementary school. *Science Education, 74*(4), 421-431.

Tobin, K., Briscoe, C., & Holman, J. R. (1990). Overcoming constraints to effective elementary science teaching. *Science Education, 74*(4), 409-420.

Tobin, K., Butler Kahle, J., & Fraser, B. J. (1990). Learning science with understanding: In search of the Holy Grail? In K. Tobin, J. Butler Kahle & B. J. Fraser (Eds.), *Windows into science classrooms* (pp. 1-10). London, UK: The Falmer Press.

Tobin, K., & Gallagher, J. J. (1987). What happens in high school science classrooms? *Journal of Curriculum Studies, 19,* 549-560.

Tomasini, N., & Balandi, B. (1988, April). *Conceptual change and science teacher training: A constructivist perspective.* Paper presented at the annual meeting of the American Educational Research Association, New Orleans.

Toulmin, S. (1972). *Human understanding.* Princeton, USA: Princeton University Press.

Treagust, D. F. (1986). Evaluating students' misconceptions by means of diagnostic multiple choice items. *Research in Science Education, 16,* 199-207.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal in Science Education, 10*(2), 159-169.

Treagust, D. F. (1993). The evolution of an approach for using analogies in teaching and learning science. *Research in Science Education, 23,* 293-301.

Treagust, D. F., Harrison, A. G., & Venville, G. (1993, April). *Using an analogical teaching approach to engender conceptual change.* Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Treagust, D. F., Harrison, A. G., Venville, G., & Dagher, Z. (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education, 18*(2), 213-229.

Tulip, D. F., & Lucas, K. B. (1993, January). *A methodology to reveal science cognitive frameworks of Papua New Guinea students: An introductory study.* Paper presented at the UNESCO Conference for Science Education in Developing Countries, Jerusalem, Israel.

Twoli, N. W., & Power, C. N. (1989). Major influences on science achievement in a developing country: Kenya. *International Journal of Science Education, 11*(2), 203-211.

The University of the South Pacific Bulletin (1995). *Better science education for primary schools, 28*(14), 1-3.

Vicentini-Mossori, C (1980). Common-sense knowledge and scientific knowledge. In C. P. McFadden (Ed.),. *World trends in science education* (pp. 276-281). Halifax, Canada: Itentio Institute of Education.

Villani, A. (1992). Conceptual change in science and science education. *Science Education. 76*(2), 223-237.

Vlaardingerbroek, B. (1991). Trainee teachers' ethnoscientific views of the paranormal variety and views on the role of ethnoscience in science education. *Papua New Guinea Journal of Education, 27*(2), 31-43.

de Vos, W. & Verdonk, A. H. (1996). The particulate nature of matter in science education and science. *Journal of Research in Science Teaching, 33*(6), 657-664.

Vosnaidou, S. (1991). Designing curricula for conceptual restructuring: Lessons from the study of knowledge acquisition in astronomy. *Journal of Curriculum Studies, 23,* 219-237.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24,* 535-585.

Vulliamy, G. (1988). Third world schools. In S. Briceno and D. C. Pit (Eds.), *New ideas in environmental education* (pp. 143-157). London, UK: Croom Helm.

Vulliamy, G. (1990). The potential of qualitative educational research strategies in developing countries. In G. Vulliamy, K. Lewin & D. Stephens (Eds.), *Doing educational research in developing countries* (pp. 7-27). London, UK: The Falmer Press.

Vygotsky, L. S. (1962). *Thought and language* (E. Hanfman & G. Vakar, Eds & trans.), Cambridge, MA: MIT Press.

Vygotsky, L. S. (1986). *Thought and language* (A. Kozulin, trans.). Cambridge, MA: MIT Press.

Vygotsky, L. S. (1987). *The collected works of L. S. Vygotsky.* In R. W. Reiber & Carton (Eds.), New York: Plenum.

Waldrip, B. G., & Giddings, G. J. (1993, April). *Educational productivity and science education within a developing country.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Watters, J. J., & Ginns, I. S. (1994a, July). *A reassessment of students' reasoning on a projectile motion problem: A case study of preservice teacher education students.* Paper presented at the annual meeting of the National Association of Research in Science Teaching, Anaheim, CA.

Watters, J. J., & Ginns, I. S. (1994b, July). *Science anxiety and self-efficacy among preservice primary teachers: Origins and remedies.* Paper presented at the annual meeting of the Australasian Science Educators Research Association, Hobart, Australia.

Watters, J. J., & Ginns, I. S. (1995, April). *Origins of, and changes in preservice teachers' science teaching self efficacy*. Paper Presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Watts, D. M., & Zylbersztajn, A. (1981). A survey of some children's ideas about force. *Physics Education, 16,* 360-365.

Webb, P. (1992). Primary science teachers' understanding of electric current. *International Journal of Science Education, 14*(4), 423-429.

Webb, N., & Cullian, L. (1983). Group interactions and achievement in small groups: Stability over time. *American Educational Research Journal, 13,* 21-39.

Westerback, M. E. (1984). Studies on anxiety about teaching science in preservice elementary teachers. *Journal of Research in Science Teaching, 21,* 937-950.

White, R., & Gunstone, R. (1992). *Probing understanding.* London, UK: The Falmer Press.

Whitehead, C. (1986). *Education in Fiji since independence: A study of government policy*. Wellington, NZ: New Zealand Council for Educational Research.

Whittaker, M., (1980). They're only playing: The problem of primary science. *School Science Review, 61,* 216, 556-560.

Wier, E. (1987, April). *Primary teachers' perceptions of barriers to teaching science.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington DC.

Williamson, V. M., & Abraham, M. R. (1995). The effect of computer animation on the particulate mental models of college chemistry students. *Journal of Research in Science Teaching, 32*(5), 521-534.

Wragg, E. C., Bennett, S., & Carré, C. (1989). Primary teachers and the national curriculum. *Research Papers in Education, 4*(3), 17-37.

Yager, R. E. (1991) The constructivist learning model: Towards real reform in science education. *The Science Teacher, 58*(6), 52-58.

Yakubu, J. M. (1994). Integration of indigenous thought and practice with science and technology: A case study of Ghana. *International Journal of Science Education, 16*(3), 343-360.

Yates, J., Bessman, M., Dunne, M., Jerston, D., Sly, K., & Wendelboe, B. (1988). Are conceptions of motion based on a naive theory or prototypes? *Cognition, 29,* 251-275.

Za'rour, G. I. (1975). Science misconceptions amongst certain groups of students in Lebanon. *Journal of Research in Science Teaching, 12,* 385-391.

Zeitoun, H. H. (1984). Teaching scientific analogies: A proposed model. *Research in Science and Technology Education, 2*(2), 107-125.

Zuzovsky, R., Tamir, P., & Chen, D. (1989). Specialised science teachers and general teachers and their impact on student outcomes. *Teaching and Teacher Education, 5*(3), 229-242.

Appendicies

Appendix A

The Science Concept Survey Instrument Employed during the Prevalence Phase of the Data Collection showing the Response Frequencies of Indian (bold) and Fijian Students (*denotes 'scientific view')

LTC **Matter and how it changes** **Concept Survey**

Full name...Male / Female
Please note this is **not** a test. This is a survey to help in the preparation of new teaching materials for you to learn from. For each statement, **circle** the response you feel is appropriate. If you are not sure about the answer or please circle "not sure" rather than guessing. Please give a reason for the response you have chosen. A sample item is shown below:

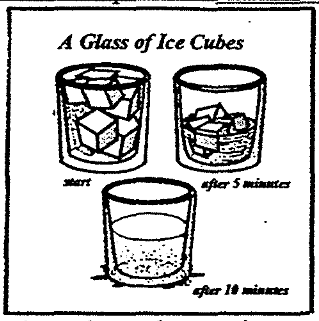
A. Cane toads belong to the group of animals called amphibians.

true **false** **not sure**

Reason: Because they have to return to water to reproduce

Survey questions

The drawing on the right shows ice cubes in a glass at the start then after 5 and 10 minutes. Use this drawing to answer questions 1-4.



1. The ice cubes in the glass release heat energy when they change into water.

true (42) (40) **false (29)** (16)* **not sure (2)** (14)

Reason:

2. The particles which make up the ice cubes are constantly vibrating.

true (22) (27)* **false (39)** (17) **not sure (12)** (26)

Reason:

3. The water droplets on the outside of the glass after 10 minutes have come from the atmosphere.

true (63) (44)* **false (8)** (22) **not sure (2)** (4)

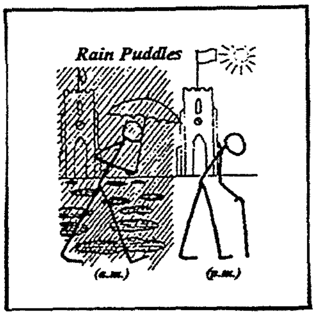
Reason:

4. High humidity around the ice cubes has caused them to melt.

true (46) (47) **false (13)** (7)* **not sure (14)** (16)

Reason:

The drawing on the right shows a change in the weather conditions between the morning and afternoon. Use the drawing to answer questions 5 & 6.



5. The puddles of water have disappeared in the afternoon because they have been absorbed by the sun's rays.

true (49) (49) **false (22)*** (14) **not sure (2)** (7)

Reason:____

____

6. Both heat and light energy are needed for evaporation to take place.

true (34) (43) **false (33)** (19)* **not sure (6)** (8)

Reason:____

____

The drawing on the right shows a kettle which has been boiling for some time. Use this drawing to answer questions 7-10.

7. The bubbles you can see inside the kettle are made of air.

true (52) (47) **false (17)** (13)* **not sure (4)** (10)

Reason:____

____

8. When water is heated above a certain temperature it will change into air.

true (52) (59) **false (19)** (5)* **not sure (2)** (6)

Reason:____

____

9. The gas coming out of the spout of the kettle will turn into water when it is cooled.

true (70) (64)* **false (3)** (5) **not sure (0)** (1)

Reason:____

____

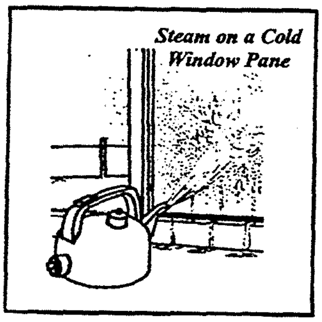
10. The heat creates a vacuum in the boiling water.

true (31) (29) **false (12)** (4)* **not sure (30)** (37)

Reason:____

____

The drawing on the right shows steam from a boiling kettle hitting a cold window pane. Use this drawing to answer questions 11-13.

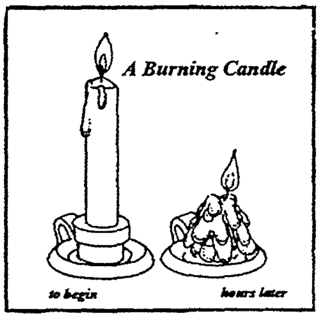


11. When the steam leaves the boiling kettle, it is attracted to the cold window pane.
true (45) (34) **false (11)** (22)* **not sure (17)** (14)
Reason:____

12. As the particles of steam touch the window they begin to move more slowly.
true (43) (38)* **false (16)** (10) **not sure (14)** (22)
Reason:____

13. Some of the water has appeared on the window because the heat from the kettle has caused the glass to 'sweat'.
true (8) (37) **false (57)** (27)* **not sure (8)** (6)
Reason:____

The drawing on the right shows a candle a few minutes after lighting and some hours later. Use this drawing to answer questions 14-19.



14. After a few hours the candle will weigh less.
true (30) (29)* **false (42)** (26) **not sure (1)** (15)
Reason:____

15. When the wax melts, it changes to water and evaporates.
true (9) (15) **false (57)** (44)* **not sure (6)** (11)
Reason:____

16. The process of burning a substance produces only heat and light.
true (17) (29) **false (51)** (24)* **not sure (5)** (17)
Reason:____

17. Melting and burning are different kinds of processes.

true (68) (53)* **false (1)** (14) **not sure (4)** (3)

Reason:____

____

18. The wax which has melted and re-solidified is the same substance as that in the original candle.

true (48) (39)* **false (17)** (22) **not sure (8)** (9)

Reason:____

____

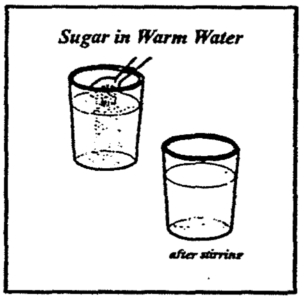
19. When a substance burns some of its matter is changed into energy.

true (52) (37) **false (5)** (3)* **not sure (16)** (30)

Reason:____

____

The drawing on the right shows what happens when some sugar is stirred in warm water. Use this drawing to answer questions 20-25.



20. The sugar crystals melt before they mix with the water.

true (42) (35) **false (28)** (31)* **not sure (3)** (4)

Reason:____

____

21. Some of the sugar changes into water during the process shown above.

true (26) (45) **false (39)** (15)* **not sure (8)** (10)

Reason:____

____

22. During stirring the sugar crystals gradually get smaller because they rub against the sides of the glass and other sugar crystals.

true (37) (46) **false (29)** (14)* **not sure (7)** (10)

Reason:____

____

23. After stirring most the sugar cannot be seen because the sugar particles have gone between the water particles.

true (55) (52)* **false (14)** (9) **not sure (4)** (9)

Reason:____

____

24. Some sugar crystals have not disappeared after stirring because they are too hard or too concentrated to dissolve.

true (31) (41) **false (36)** (15)* **not sure (6)** (14)

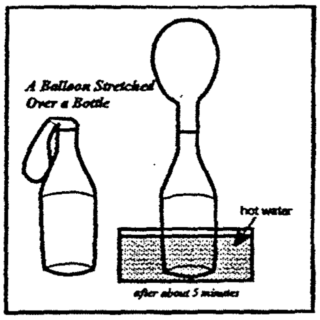
Reason:____

25. After the sugar has dissolved it is possible to get the sugar crystals back from the solution.

true (61) (37)* **false (10)** (19) **not sure (2)** (14)

Reason:____

The drawing on the right shows what happens when a bottle with a balloon stretched over it is placed in hot water for 5 minutes. The bottle does not contain any liquid. Use this drawing to answer question 26-28.



26. Heat from the water makes the air particles in the bottle lighter and they move up causing the balloon to expand.

true (53) (58) **false (18)** (4)* **not sure (2)** (8)

Reason:____

27. After 5 minutes in the hot water, there will be the same amount of air particles in the bottle and in the balloon.

true (42) (24)* **false (30)** (41) **not sure (1)** (5)

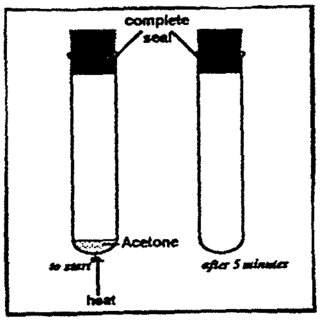
Reason:____

28. If the bottle is removed from hot water the balloon will deflate (shrink).

true (67) (58)* **false (3)** (4) **not sure (3)** (8)

Reason:____

The drawing on the right shows a sealed test tube of liquid acetone before heating and after it has been heated for 5 minutes. Use this drawing to answer questions 29-32.



29. If we weigh the test tube before and after it has been heated the weight will be the same.

true (38) (20)* **false (24)** (33) **not sure (11)** (17)

Reason:____

____

30. After heating, the acetone particles will combine with the air particles in the test tube.

true (48) (47) **false (9)** (2)* **not sure (16)** (21)

Reason:____

____

31. If we cool tube (B) it will be possible to see the liquid acetone again.

true (35) (24)* **false (9)** (11) **not sure (29)** (35)

Reason:____

____

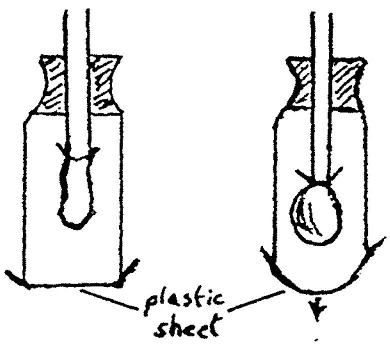
32. During heating the acetone disappears because it has passed through the glass of the test tube.

true (4) (8) **false (52)** (40)* **not sure (17)** (22)

Reason:____

____

The drawing on the right shows a balloon inside a sealed bottle before and after the plastic sheet has been pulled down. The balloon is attached to a tube which leads to the outside. Use this picture to answer question 33-36.



33. When the plastic sheet is pulled down air is sucked or pulled into the balloon.

true (60) (42) **false (3)** (4)* **not sure (10)** (24)

Reason:____

____

34. The force of gravity is involved in moving the air into the balloon.

true (23) (34) **false (23)** (5)* **not sure (27)** (31)

Reason:____

35. When the plastic sheet is pulled down the pressure inside the bottle is reduced.

true (28) (30)* **false (21)** (10) **not sure (24)** (30)

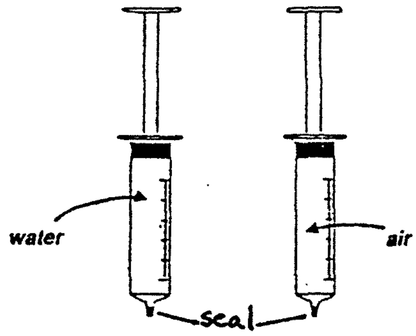
Reason:____

36. Before the sheet is pulled down there is already air in the balloon even though it is 'empty'.

true (61) (58)* **false (0)** (0) **not sure (12)** (12)

Reason:____

The drawing on the right shows two **sealed** syringes. One syringe contains water and the other contains air. Use this picture to answer question 37.

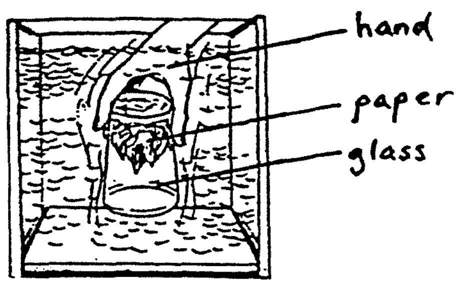


37. It would **not** be possible to push the plunger in **either** the syringe full of air **or** the syringe full of water.

true (26) (34) **false (46)** (33)* **not sure (1)** (2)

Reason:____

The drawing on the right shows a student pushing a glass containing some crumpled paper beneath the surface of a tank of water. Use this drawing to answer question 38.



38. The paper in the glass will stay dry because the force provided by the student's hand keeps the water out of the glass.

true (34) (31) **false (25)** (22)* **not sure (14)** (17)

Reason:____

Further questions about matter

39. When a metal ball is heated its particles become bigger.
true (47) (49) **false (24)** (14)* **not sure (2)** (7)

Reason:____
____

40. If enough heat is applied to the metal ball some of its particles will burst or disintegrate.
true (34) (31) **false (22)** (18)* **not sure (17)** (21)

Reason:____
____

41. If the ball is cooled after heating its particles will come closer together.
true (65) (56)* **false (3)** (5) **not sure (5)** (9)

Reason:____
____

42. There is more space between the particles of a liquid than the particles of a solid.
true (69) (59)* **false (3)** (4) **not sure (1)** (7)

Reason:____
____

43. The particles of a liquid are free to move around one another or past one another.
true (63) (53)* **false (8)** (13) **not sure (2)** (4)

Reason:____
____

44. There is air between the particles which make up a metal ball.
true (20) (20) **false (47)** (31)* **not sure (6)** (19)

Reason:____
____

45. Air has weight.
true (56) (45)* **false (13)** (12) **not sure (4)** (13)

Reason:____
____

46. Gas pressure is caused by gas particles hitting the sides of a container

true (42) (31)* **false (7)** (6) **not sure (24)** (33)

Reason:____

____

47. The pressure of the air gets higher as the humidity gets higher.

true (38) (40) **false (11)** (8)* **not sure (24)** (22)

Reason:____

____

48. When a substance loses energy it becomes lighter.

true (45) (51) **false (13)** (0)* **not sure (15)** (19)

Reason:____

____

49. The particles that make up matter are living.

true (29) (25) **false (26)** (14)* **not sure (18)** (31)

Reason:____

____

50. When a substance is heated, its particles become positively charged and repel each other.

true (28) (40) **false (8)** (6)* **not sure (37)** (24)

Reason:____

____

Appendix B

Fiji Basic Science Course Objectives Relating to Matter, Solubility, Heat and Pressure

(a) Matter and how it changes

Students should be able to:

understand the term 'states of matter'

classify substances as solids, liquids, or gases.

state the characteristics of solids, liquids, and gases.

state that solids will change to liquids when heated

state that liquids will changes to gases when heated

state that cooling gases turns them to liquids

state that cooling liquids turns them to solids

use the words melting, freezing, evaporation, and condensation correctly

identify changes where new substances are made

state that new substances can be made either by heating substances or by simply mixing substances together

state that when new substances are made, it is not easy to reverse the reaction.

(b) Solubility

Students should be able to:

use correctly the words dissolved, solution, solute, solvent, concentrated, diluted and saturated.

prepare a solution of salt water

state that powder solids dissolve faster than lump solids

identify a saturated solution

identify which solids dissolve?

classify solids as soluble or insoluble

classify liquids into solutions or pure liquids by evaporation

explain that pure water can be obtained from a solution by evaporating and then condensing

use the word 'distillation' to describe the above process.

describe the movement of water via the water cycle

relate the processes of evaporation and condensation to natural events.

(c) Heat

Students should be able to:

state that heat can travel through solids

use the word 'conduction' to describe this process

state that some solids conduct heat at a faster rate than others

use the idea of heat conduction to explain some simple observations

classify substances as conductors or insulators.

correctly use the words expand and contract

state that heat generally causes solids to expand

observe changes caused by heating and infer that a change in length occurred.

discuss the shattering of brittle materials such as glass on fast heating and cooling

relate this to the shattering of rocks to form soil

state that 'compound' materials often bend when heated because of unequal expansion rates

discuss the importance of expansion and contraction in the world today

describe the changes that occur when we heat and cool a gas?

use an air thermometer. (Fiji Ministry of Education, 1981)

(d) Pressure

Students should be able to:

use the term 'vacuum' to describe the absence of air in a space

recognise that air can be compressed while liquids cannot

describe the structure and functioning of a syringe or a simple pump

show that more air can be pumped into a container

state that forces can be carried through water.

state that air exerts pressure

explain some of the effects of air pressure

explain how air pressure changes with height. (Fiji Ministry of Education, 1984).

<u>Some Major Scientific Principles informing these Objectives</u>

Changes in matter

1. All matter is made up of particles either atoms or molecules.
2. There are forces of attraction between these particles in any given substance:

(a) In solids the forces of attraction between the particles tend to be arranged in an orderly way.

(b) In a liquid the forces of attraction between the constituent particles are weaker and the particles tend to be disordered.

(c) In gases the particles are free to move relative to each other and are disordered.

4. Changes of state are associated with changes in the velocity of the particles which make up a substance:

(a) When a substance changes from a solid to a liquid or from a liquid to a gas, the particles move more rapidly as they have more (kinetic) energy.

(b) When a substance changes from a gas to a liquid or a liquid to a solid, the particles the particles move more slowly as they have less (kinetic) energy.

5. When a substance changes from one state to another the composition of the particles (atoms or molecules) remains the same.

Pressure

1. Gas pressure is the combined effect of the gas molecules colliding with the walls of the containing vessel.

2. Heating a gas increases the number of collisions, per second, per unit area and therefore increases the gas pressure.

Heat

1. When heat is applied to a substance the heat is absorbed and some of it is transferred to kinetic energy which increases the velocity of the particles. Conversely, the loss of heat by a substance reduces the velocity of the particles.

Physical and chemical change

1. A physical change is any change in a substance in which the structure and composition of the particles remains the same.

2. A chemical change is a change in which the structure and composition of the particles is altered.

Solubility

1. Dissolving a solute in a solvent is a physical change and the solute can be recovered from the solution. e.g. by heating.

2. When no more solute will dissolve in a solvent at a given temperature and pressure the solution is said to be saturated.

(Adapted from Linke & Venz, 1978)

Appendix C

Concept Profile Inventory (CPI) for QUT Students Involved in the Pilot Study.

A. Conceptions about changes in the state of matter

Scientific Conceptions

A.1.1 Changes of state are usually associated with the effect of temperature change on matter (4)

"The ice absorbs the heat in the atmosphere...until it turns into water." **S2**

A.1.2 Changes of state are associated with the energy (velocity) of the particles which make up a substance (3)

"Because it's being heated the molecules are becoming more active, therefore they are breaking apart...melting down to a more liquid form." **S3**

A.1.3 Intermolecular distances decrease from gases through liquids to solids (7)

"In the air the gas molecules are going to be more spread apart than in the liquid." **S3**

A.1.4 Condensation is derived from water vapour in the atmosphere (2)

"It's (condensation) water from the air." **S9**

Alternative Conceptions

A.2.1 Melting is due to something other than ice absorbing heat energy (1)

"...it's losing its coolness to the heat of the atmosphere." **S5**

A.2.2 Condensation is a remnant of evaporation (1)

"...and condensation is just residue that's been left on the glass from evaporation...just water droplets that are left" **S1**

A.2.3 Condensation is due to leakage (2)

"It (condensation) comes out of the glass...the cold water in it perspires on the outside." **S10**

A.2.4 Evaporation is associated with some form of absorption or force (3)

"The sun probably dries it up just so it's powerful, stronger than the rain" **S4**

B. Conceptions about physical and chemical change and conservation of mass

Scientific Conceptions

B.1.1 When a substance changes from one state to another the composition of its particles remains the same (3)

"...it (steam) has to be made of water because that's where it comes from." **S7**

B.1.2 Matter is neither created nor destroyed during chemical or physical changes (5)

"The acetone changed form but the same amount of molecules was present all the time."**S7**

B.1.3 Burning and melting are different types of processes (1)

"...burning you can't change back to its original properties, but melting you can." **S9**

Alternative Conceptions

B.2.1 Mass is lost or gained during a physical change (3)

"It (the mass) will be less after 5 minutes...because the acetone has evaporated." **S2**

B.2.2 Matter is destroyed by burning (3)

"I'd say (after burning) most of it would cease to exist..." **S1**

B.2.3 Physical change associated with one substance changing into another (6)

"...they break apart, they're not a water molecule...they break into oxygen and hydrogen.." **S3**

B.2.4 A physical change in a substance is accompanied by a change in the size and/or number of the particles (2)

"They (water molecules being heated) expand or get more of them, multiply." **S4**

B.2.5 There is no distinct difference between the processes of burning and melting (2)

"...burning and melting...it probably is the same." **S4**

B.2.6 A change of state viewed as a chemical change (1)

"Because they change their molecular structure then they get evaporated into the atmosphere." **S5**

C. Conceptions about pressure

Scientific Conceptions

C.1.1 Air occupies space (4)

"The air that's inside the beaker will protect it (the paper) from the water." **S10**

C.1.2 Particles of gas exist within a vacuum (2)

"But like the particles are all apart and there's nothing between them." **S10**

C.1.3 Gas pressure is the combined "push" of gas particles (1)

"They (gas molecules) start bouncing of everything so they push the water up and out."**S3**

C.1.4 Increased volume for a fixed mass of gas decreases pressure (2)

"When you pull down on the diaphragm the pressure inside will decrease." **S3**

C.1.5 Reducing the number of gas molecules per unit volume decreases pressure (2)

"The (air) molecules...there's more space so they spread out." **S3**

Alternative Conceptions

C.2.1 The molecules within a gas do not move randomly (2)

"...there would be more gas in the balloon (than the connecting bottle)"**S1**

C.2.2 There is some form of matter between the molecules of a gas (5)

"Whatever is between the air particles might have absorbed the acetone." **S10**

C.2.3 A gas is viewed as continuous matter (1)

"...because air particles are whole and water can't get through air." **S10**

C.2.4 Air movement attributed to 'sucking' or air being pulled (3)

"...you're creating a bigger space in the cavity and that's sucking the air in..." **S7**

C.2.5 A vacuum is not entirely free of matter (1)

"I think the syringe with air in it will form a vacuum and you won't be able to push it closed." **S1**

D. Conceptions about heat

Scientific Conceptions

D.1.1 Matter expands when heated (2)

"Heated metal expands." **S6**

D.1.2 Heating a substance causes the molecules to move more rapidly (3)

"Because (after heating) the molecules are racing around at a higher speed." **S7**

D.1.3 During heating particles do not change their size or structure (1)

"I don't think they'd (the atoms) would change in size" **S1**

D.1.4 Heating causes atoms to vibrate more rapidly and results in expansion (3)

"...the flame heats up the ball and the molecules within are vibrating more vigorously, and because they're vibrating, it expands the actual metal ball." **S1**

Alternative Conceptions

D.2.1 When a substance is heated the atoms or molecules expand (4)

"Heated molecules expand." **S7**

E. Conceptions about solubility

Scientific Conceptions

E.1.1 Dissolving a solute in a solvent is a reversible physical change (3)

"If you boiled off the water you could get it (the sugar) back again." **S6**

E.1.2 Saturation occurs when no more solute will dissolve in a solvent (4)

"Maybe the water's saturated with sugar and can't hold anymore." **S5**

Alternative Conceptions

E.2.1 In a solution the particles of solute are absorbed by the particles of solvent (3)

"The sugar is somehow being incorporated into the water molecules" **S1**

E.2.2 Dissolving is an irreversible process (1)

"Once it's dissolved, that's a permanent change." **S1**

E.2.3 Some crystals within a solute are too concentrated or 'strong' to dissolve (2)

"...cause it's crystal and solid matter and so it's stronger than the liquid." **S4**

E.2.4 Saturation is due to incompatibility (1)

"They're (the sugar crystals) are not compatible to the water." **S10**

E.2.5 Saturation is a an inevitable phenomena (1)

"Because things always go to the bottom...there has to be some remnants left over like in a creek bed." **S2**

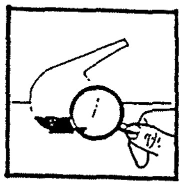
Appendix D

Handout on Pressure provided for the Students which contained the 'Scientific View'

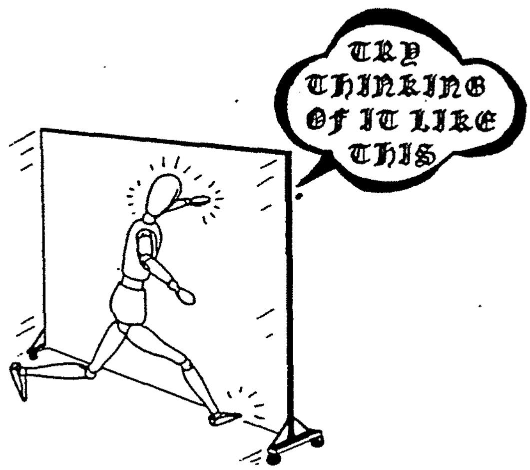
(Pendlington, Palacio & Summers, 1993)

PARTICLES EXERT A PRESSURE

Scientists hold the view:



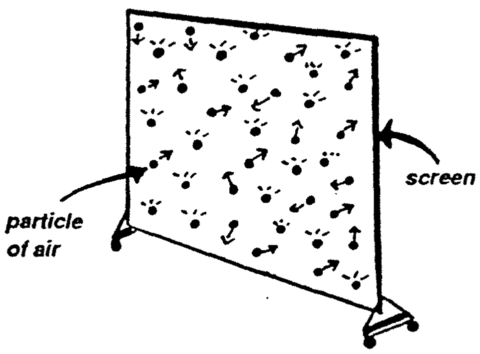
that particles of gases collide with other objects, such as the walls of their container;
that each time a particle collides in this way, it pushes against the object;
that this push is a force;
that, at any moment in time, there are millions of particles pushing against the walls of their container;
that scientists measure the **total** push by these millions of particles on a square centimetre of the wall of the container;
that scientists call this **pressure**.



Imagine a wooden screen dividing a room. The screen has wheels so it can be moved around.

A child is running towards the screen and collides with it. What happens to the screen?

It moves because the child has pushed the screen, pushing the screen is another way of saying that a force has acted on it.



Now imagine the same room and screen, but this time instead of one child there are millions of air particles in the room.

Scientists hold the view that the particles are colliding with the screen and causing a pressure in the way that the child produced a force when he collided with the screen.

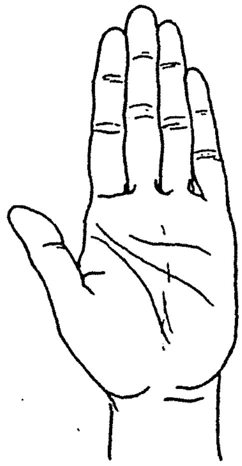
But the screen doesn't move!

But if the scientists views are correct, and the particles of air **are** colliding with the screen and causing pressure, why doesn't the screen move?

Is there something more complex here which is missing from the analogy?

We want **you** to try to work this out.
To help you try the activity 'Blowing" on the next page.

ACTIVITY 10 - BLOWING

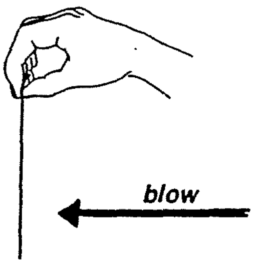


You will need:
a sheet of A4 paper

Hold your hand up in front of you with the palm towards you.
Can you feel any pressure from air particles on your hand?

Now blow gently onto your palm. Can you FEEL a pressure now? Is your hand moving? Why not?

Let's see if we can SEE pressure moving something.



Repeat the above with the sheet of A4 paper.
Hold it still first, then blow onto one side.
Can you SEE the paper moving?

Now discuss this with a colleague or the group and try to work out what could be happening.

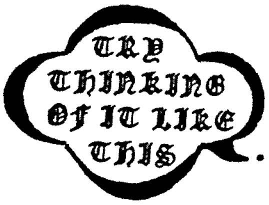
Remember the analogy of the child colliding with the screen to make it move. How does this fit with blowing the piece of paper to make it move?

Can you explain why the screen when left alone, your hand and the paper before you blew stayed still?

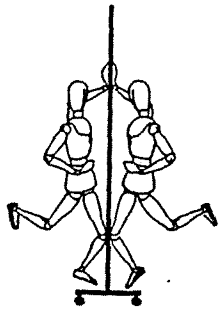
Try to extend the analogy of the child colliding with the screen so that the screen does NOT move even though a child is colliding with it. There could be several ways of doing this. Can you think of one which would be like the air particles colliding with the screen.

MAKE A DRAWING TO SHOW WHAT COULD BE HAPPENING TO THE PARTICLES ON EITHER SIDE OF THE SCREEN IN THE SPACE BELOW.

MORE ABOUT PRESSURE



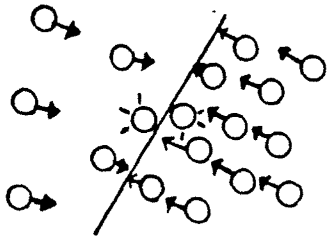
To make the screen move, the child collided with it. How can we keep the screen stationary when the child is colliding with it?



We would need to provide an equal force on the other side at the same time. So we need to imagine two children, both the same mass, running at the same speed and colliding at the same time on opposite sides of the screen.

This is like the particles of air in the room. The pressure on both sides of the screen is equal so the screen does not move when left alone.

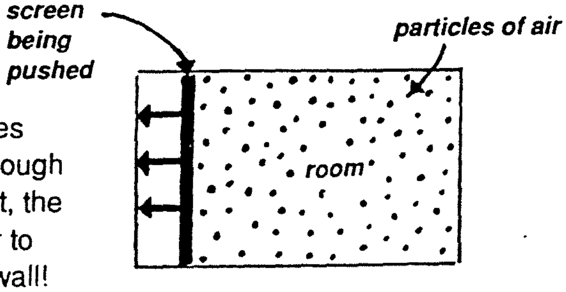
When you blew the sheet of paper, you upset the balance. The particles of air on one side were exerting more pressure so the paper moved. **This must mean that either the number and/or speed of collisions on that side has increased.**



Blowing the particles makes them move faster, so they hit the paper at a greater speed. This means that the pressure on that side of the paper is greater and the paper moves.

When you blew on your hand you could feel the increase in the rate of the collisions but your hand was too heavy to be moved, unlike the paper, which was much lighter.

The pressure that particles of gases and liquids can exert can be considerable. Remember the more the balance is disturbed, the greater the effect of the collisions of the particles.



If you could remove all of the particles from one side of the screen, even though it would be a very large heavy object, the screen would move. It would appear to have been 'sucked' to the opposite wall!

Appendix E

The Concept Profile Inventory (CPI) for LTC Fijian students involved in the main study. (*Number of students holding that conception)

A. Conceptions about changes in the state of matter

Scientific Conceptions

A.1.1 Changes of state are usually associated with the effect of temperature change on matter (7)*

"Because of the heat the ice begins to melt..." **FF2**

A.1.2 Changes of state are associated with the energy (velocity) of the particles which make up a substance (1)

"When you heat it the particles in the solid vibrate." **FM1**

A.1.3 Intermolecular distances decrease from gases through liquids to solids (5)

"solid particles are very close together and liquid particles have a bit of space and the air much larger spaces." **FF5**

A.1.4 Condensation is derived from water vapour in the atmosphere (4)

"(Condensation) its from the air around the beaker." **FF1**

A.1.5 Energy is gained or lost when matter changes state (0)

Alternative Conceptions

A.2.1 Change of state associated with something other than temperature change (2)

"The humidity causes the ice cubes to melt." **FM5**

A.2.2 Intermolecular spaces decrease from solids through liquids to gases (1)

"The particles tend to come together I mean sort of contract yes during melting they join together." **FF3**

A.2.3 Condensation is due to leakage or attraction (6)

"most probably it (condensation) might have come though the glass." **FF3**

A.2.4 Evaporation associated with absorption (5)

"...the liquid goes back to the sun...I think by (the sun's rays) absorbing it." **FF4**

A.2.5 Particles viewed as living entities (1)

"I think the particles are living." **FM5**

A.2.6 During evaporation different gas particles become bound together (1)

"here (during evaporation) it's a matter of air and the acetone being joined together, the particles bind together." **FF1**

A.2.7 Condensation comes directly from ice (1)

"Maybe a little of it (condensation) comes from inside from the ice cubes here." **FM5**

A.2.8 Evaporation occurs because heating makes the particles of a liquid lighter(1)

"When the particles of water is being heated up they tend to get light and rise up into the air." **FM1**

A.2.9 Evaporation associated with reflection (0)

A.2.10 A vacuum is created within a liquid during boiling (0)

A.2.11 Heat causes particles to come closer together (0)

A.2.12 Heat is released during melting (0)

B. Conceptions about physical and chemical change and conservation of mass

Scientific Conceptions

B.1.1 When a substance changes from one state to another the composition of its particles remains the same (2)
"(Steam is) water turning into gas." **FM4**

B.1.2 Matter is neither created nor destroyed during chemical or physical change(3)
"it has just changed from liquid to gas so I suppose it (the mass) would be the same." **FF3**

B.1.3 Burning and melting are different types of processes (5)
"I think you can't reverse burning but you can reverse melting." **FM1**

Alternative Conception

B.2.1 Mass is lost or gained during a physical change (6)
"Because in liquid form it (acetone) is much heavier than in gaseous form." **FF5**

B.2.2 Matter is destroyed by burning (1)
"When something burns it is completely destroyed..." **FF3**

B.2.3 Physical changes associated with one substance changing to another (5)
"...maybe because the hot air when it touches a cold substance...its particles turn to water because of something which happens in nature." **FM1**

B.2.4 There is no change in the mass of a burning candle (4)
"They would be the same (mass of candle before and after burning)." **FF6**

B.2.5 The bubbles in a boiling kettle are formed from air (9)
"They are made of air particles (the bubbles)." **FM6**

B.2.6 Physical change is not reversible (2)
"You wouldn't get any change (cooling acetone vapour) it would stay as gas." **FM4**

B.2.7 The process of melting requires the presence of oxygen (1)
"Maybe it (melting) involves oxygen too." **FF5**

B.2.8 When a substance loses energy it loses mass (0)

C. Conceptions about pressure

Scientific conceptions

C.1.1 Air occupies space (8)
"The air particles inside prevented it from getting wet." **FF2**

C.1.2 Particles of gas exist within a vacuum (3)
"There's a vacuum between the particle." **FF1**

C.1.3 Gas pressure is due to the combined "push" of gas particles (0)

C.1.4 Increased volume for a fixed mass of gas decreases pressure (0)

C.1.5 The molecules within a gas move at random (0)

Alternative conceptions

C.2.1 The molecules within a gas do not move randomly (5)
"I think more of them will be up here (air particles in the balloon)." **FM1**

C.2.2 There is some form of matter between the particles of a gas (2)
"There must be something in that space (between the air particles) because if there's nothing we will die because we need air to breathe." **FM1**

C.2.3 Gas viewed as continuous rather than particulate (1)
"Some of the air must have gone out (of the syringe), because if there's some inside you wouldn't be able to do this (squeeze the plunger)." **FF3**

C.2.4 Air movement attributed to 'sucking' or air being pulled (3)
"I think the air is sucked into the balloon." **FM6**

C.2.5 Air lacks physical characteristics (3)
"You can't really see gas...and it's weightless." **FM5**

C.2.6 High pressure associated with humidity (1)
"...so the moisture that's present...will cause the pressure to rise." **FM6**

C.2.7 Air movement attributed to gravitational pull (0)

C.2.8 Increased volume for a fixed mass of gas increases pressure (0)

C.2.9 The force supplied by the human hand prevents the water entering a submerged inverted jar (0)

D. Conceptions about heat
Scientific conceptions

D.1.1 Matter expands when heated (8)
"The ball expanded when it was heated." **FF3**

D.1.2 Heating a substance causes the particles to move apart and more rapidly (5)
"The particles...when the ball was heated the particles they sort of spread out." **FF3**

D.1.3 During heating particles do not change their size or structure (4)
"They just move apart, they don't get bigger." **FM3**

Alternative conceptions

D.2.1 When a substance is heated the atoms or molecules expand (5)
"The particles move apart and get bigger." **FF5**

D.2.2 Heat energy can be transformed to matter (1)
"When it (heat) gets inside it will turn into air..." **FF4**

D.2.3 Particles come together then spring apart during heating (1)
"The particles they push off each other like this (bouncing fists together then far apart)." **FM4**

D.2.4 Air within a solid causes it to expand upon heating (1)
"Maybe some air particles in that solid ball tried to move out and therefore made the ball big...it pushed the solid a bit outwards." **FM1**

D.2.5 Heating causes particles of matter to burst resulting in expansion (1)
"They actually burst just like that (opening his hand) and expand." **FM4**

D.2.6 Heating causes particles to become charged (0)

E. Conceptions about solubility

Scientific conceptions

E.1.1 Dissolving a solute in a solvent is a reversible physical change (6)
"after some time the water will evaporate and the sugar will be there." **FF6**

E.1.2 Saturation occurs when no more solute will dissolve in a solvent (5)
"I guess there's no more space so it (the water) just can't take any more sugar." **FM4**

E.1.3 A solution consists of one substance mixed thoroughly with another (4)
"The sugar particles just mixes with water...just mixes in between." **FM4**

Alternative conceptions

E.2.1 Dissolving associated with melting (2)
"The sugar (in water) will melt...the sugar particles have turned to liquid." **FF3**

E.2.2 Dissolving is an irreversible process (5)
"Because water is a liquid and you just can't get anything back." **FM4**

E.2.3 Some crystals within a solute are too concentrated or 'strong' to dissolve (2)
"These particles here they're too closely attached and it doesn't allow space for the water to get through and make it soluble." **FM6**

E.2.4 During dissolving sugar absorbs water (1)
"Sugar absorbs water and causes the particles to disintegrate and eventually it turns to liquid." **FM6**

E.2.5 During dissolving the solute changes chemically (1)
"It (the sugar) changes into liquid...it changes into water." **FF5**

E.2.6 Saturation explained as impurities (0)

E.2.7 Dissolving attributed to abrasion or attrition (0)

E.2.8 Dissolving attributed to air spaces between water particles (0)

Appendix F

The Concept Profile Inventory (CPI) for LTC Indian students involved in the main study. (*Number of students holding this conception)

A. Conceptions about changes in the state of matter

Scientific Conceptions

A.1.1 Changes of state are usually associated with the effect of temperature change on matter (11)*
"The water that's in the puddles gets hot so as a result it evaporates." **IF3**

A.1.2 Changes of state are associated with the energy (velocity) of the particles which make up a substance (3)
"They (particles) move faster when they are heated." **IM4**

A.1.3 Intermolecular distances decrease from gases through liquids to solids (10)
"Liquid particles have got less space between them as compared to gas particles." **IF4**

A.1.4 Condensation is derived from water vapour in the atmosphere (8)
"That (condensation) is probably water from the surroundings." **IM1**

A.1.5 Energy is gained or lost when matter changes state (2)
"Condensation takes place because there is heat release." **IF4**

Alternative Conceptions

A.2.1 Change of state associated with something other than temperature change (2)
"due to atmospheric pressure the droplets (of condensation) was formed." **IF1**

A.2.2 Intermolecular spaces decrease from solids through liquids to gases (1)
"Once ice cubes they melt, the particles they come closer together...once it's melted it has taken less space." **IF1**

A.2.3 Condensation is due to leakage or attraction (1)
"Heat from the inside of the glass, that causes the water (condensation) to move out through the glass." **IM2**

A.2.4 Evaporation associated with absorption (2)
"The water particles are absorbed by the air particles." **IF1**

A.2.5 Particles viewed as living entities (1)
"The energy provides the strength to the particles...I think it (the particle) could be a living thing." **IM3**

A.2.6 During evaporation different gas particles become bound together (0)

A.2.7 Condensation comes directly from ice (0)

A.2.8 Evaporation occurs because heating makes the particles of a liquid lighter(0)

A.2.9 Evaporation associated with reflection (1)
"Rays get directly in contact with the puddles...and the reflection of the rays causes it to dry up." **IF2**

A.2.10 A vacuum is created within a liquid during boiling (1)
"The heat creates a vacuum so the air finds space to go out." **IF5**

A.2.11 Heat causes particles to come closer together (1)
"Heat causes acetone particles to come closer together and form liquid." **IM1**

A.2.12 Heat is released during melting (2)
"The ice has melted and has released heat." **IF4**

B. Conceptions about physical and chemical change and conservation of mass

Scientific Conceptions

B.1.1 When a substance changes from one state to another the composition of its particles remains the same (3)
"Water particles they form steam and come out of the kettle." **IF4**

B.1.2 Matter is neither created nor destroyed during chemical or physical change(9)
"Nothing is lost it's just a change of state (melting)." **IF3**

B.1.3 Burning and melting are different types of processes (11)
"Burning is a chemical change and melting is a physical change." **IM6**

Alternative Conception

B.2.1 Mass is lost or gained during a physical change (3)
"The water particles become very light and change into vapour." **IM2**

B.2.2 Matter is destroyed by burning (3)
"Due to the burning if the candle, the wax have just been destroyed." **IM3**

B.2.3 Physical changes associated with one substance changing to another (2)
"The water is changing to air" **IM4**

B.2.4 There is no change in the mass of a burning candle (6)
"It would be the same (the mass of the candle before and after burning)." **IM2**

B.2.5 The bubbles in a boiling kettle are formed from air (9)
"When water boils it gives out air." **IM5**

B.2.6 Physical change is not reversible (0)

B.2.7 The process of melting requires the presence of oxygen (0)

B.2.8 When a substance loses energy it loses mass (1)
"Most of the energy would have been lost so it (the candle) must be lighter." **IF1**

C. Conceptions about pressure

Scientific conceptions

C.1.1 Air occupies space (7)
"The air inside stops the water particles to get in." **IM4**

C.1.2 Particles of gas exist within a vacuum (7)
"I mean it's empty space between the particles of air." **IF6**

C.1.3 Gas pressure is due to the combined "push" of gas particles (3)
"The air particles have gained energy so they contact the water and the water moves out." **IF1**

C.1.4 Increased volume for a fixed mass of gas decreases pressure (3)
"When we are pulling the plastic down, the pressure inside decreases." **IF6**

C.1.5 The molecules within a gas move at random (4)
"There would be the same amount of air at the top and the bottom of the bottle." **IF3**

Alternative conceptions

C.2.1 The molecules within a gas do not move randomly (1)
"Then more (air) is up here (in the balloon)." **IF6**

C.2.2 There is some form of matter between the molecules of a gas (3)
"Water vapour and other gases (is between the particles of air)." **IF4**

C.2.3 Gas viewed as continuous rather than particulate (2)
"The air is acting like a lid cover so it doesn't let the water go in." **IM5**

C.2.4 Air movement attributed to 'sucking' or air being pulled (4)
"The air from the atmosphere is pulled inside." **IF3**

C.2.5 Air lacks physical characteristics (0)

C.2.6 High pressure associated with humidity (0)

C.2.7 Air movement attributed to gravitational pull (1)
"Gravitational pull...it's something like low pressure so air rushes in." **IM5**

C.2.8 Increased volume for a fixed mass of gas increases pressure (2)
"And the pressure once we pull it down, we're trying to increase the pressure." **IF1**

C.2.9 The force supplied by the human hand prevents the water entering a submerged inverted jar (1)
"This pressure (from the hand) is more than the pressure from the liquid...so the water cannot get inside." **IM6**

D. Conceptions about heat

Scientific conceptions

D.1.1 Matter expands when heated (8)
"Because the heat will cause the ball to expand" **IM1**

D.1.2 Heating a substance causes the particles to move apart (8)
"It (heat) adds more energy and the water particles start moving apart." **IF6**

D1.3 During heating particles do not change their size or structure (8)
"No the particles remain the same size but the space between them changes." **IF3**

Alternative conceptions

D.2.1 When a substance is heated the atoms or molecules expand (2)
"It depends on the particle but I think it gets bigger due to the heat provided." **IM3**

D.2.2 Heat energy can be transformed to matter (0)

D.2.3 Particles come together then spring apart during heating (0)

D.2.4 Air within a solid causes it to expand upon heating (0)

D.2.5 Heating causes particles of matter to burst resulting in expansion (0)

D.2.6 Heating causes particles to become charged (1)
"Heat causes the particles to get positive charges and due to the charging of the particles they repel and that's why the balloon expands." **IM1**

E. Conceptions about solubility

Scientific conceptions

E.1.1 Dissolving a solute in a solvent is a reversible physical change (9)
"Get one evaporating dish put the liquid there and evaporate it, you will get the crystals back." **IM6**

E.1.2 Saturation occurs when no more solute will dissolve in a solvent (7)
"Because the mixture cannot hold that much of solute." **IF3**

E.1.3 A solution consists of one substance mixed thoroughly with another (8)
"The sugar particles mix with the water particles." **IM4**

Alternative conceptions

E.2.1 Dissolving associated with melting (1)
"Sugar melts then mixes with the water." **IM5**

E.2.2 Dissolving is an irreversible process (2)
"It's a permanent change...it's impossible to reverse, I think." **IM3**

E.2.3 Some crystals within a solute are too concentrated or 'strong' to dissolve (1)
"These crystals must be very hard packed that hasn't got dissolved." **IM6**

E.2.4 During dissolving sugar absorbs water (0)

E.2.5 During dissolving the solute changes chemically (0)

E.2.6 Saturation explained as impurities (1)
"It will be dust...that's why it didn't dissolve in the water." **IM3**

E.2.7 Dissolving attributed to abrasion or attrition (1)
"The crystals get smaller in size because they are being rubbed with the (sugar) particles and with the water and with the surface of the beaker." **IF3**

E.2.8 Dissolving attributed to air spaces between water particles (1)
"Dissolving that means that the sugar particles they take the air spaces which is in the water particles." **IM1**

Appendix G

Instructions Provided to Judges who Validated the Transcript Analyses using the CPI, along with a Copy of Transcript FF3.

Instructions to Judges

As part of my PhD research, I conducted some interviews with students from LTC. During these interviews the students were shown a series of cards (copies of which are attached) and asked to explain certain things. A profile was then made of the scientific conceptions and the misconceptions or alternative conceptions they expressed in their answers. I would like to validate findings of the interviews, and to do that I need other people with a science background to help. I would be most grateful if you could go through the two transcripts for the responses to Cards 1-4 and beside each response mark if the student has used particles (P) and energy (E) and whether they have used a partial or complete molecular model (PM) or (CM). They may of course not use any of these. If they do not use particles then they cannot have used a molecular model. Please use the criteria below to guide you.

Criteria:

Energy = Any reference to energy not just the word "energy" e.g., reference to heat.

Particles = atoms, molecules or particles.

Partial molecular model = No explicit reference to the relationship between energy and particles e.g., the particles move apart.

Complete molecular model = Explicit reference to the relationship between particles and energy e.g., the particles gain energy when heated.

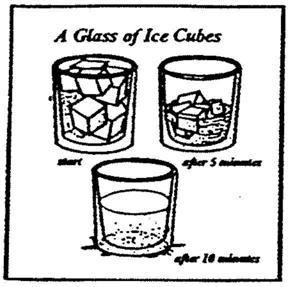
The second part of the validation involves going through the responses to Cards 1-4 and marking any scientific conceptions (✓) or misconceptions (**X**), then seeing if they have been represented in the profile. If the conception is represented in the profile please write the code, e.g., **A.1.4**, beside that conception in the transcript. I have included an example for card 1 of transcript 1.

Many thanks for your help.

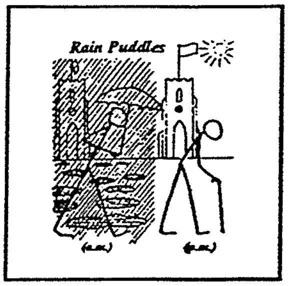
Neil.

Transcript 1 - FF3 (I=interviewer; S=student)

CARD 1

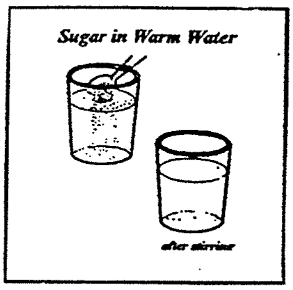


CARD 2



CARD 3

CARD 5



Card 1

I: What do you see happening in the glass?
S:...They're melting...the ice cubes.
I: What actually happens during melting? If I asked you to give me as scientific an explanation of melting as possible, what would you say?
S: Em solid's turning to liquid.
I: I see...why does that happen?
S:...I'm sorry I'm not sure
I: That's OK.
I: On the outside of the glass, what do you see on the outside of the glass?
S: Vapour...water vapour.
I: Where do you think that has come from?
S: (No response).
I: You know when you take a bottle of water from the fridge you get that on the outside, do you know where that comes from?
S: From the atmosphere? ✓ **A (A.1.4)**
I: Do you know why it forms?
S: Because condensations taking place?
I: Do you know why condensation is taking place?
S: No(laughs).

Card 2

I: If you look at this card, can you tell me where the puddles have gone in the afternoon?
S: (No response).
I: You know when it rains you get puddles formed.
S: Absorbed...the soil
I: Supposed this wasn't soil, say this was concrete?
S: OK absorbed by the sun...or the atmosphere.
I: Which do you think?
K The sun.
I: Could you say any more about how that happens?
S: (No response).
I: You understand the picture?

S: Yeah...no that's all I can say.

Card 3

I: This one shows a glass kettle which is boiling, what do you see inside the kettle?
S: Bubbles.
I: What do you think the bubbles are made of?
S: There are some spaces between the liquids.
I: What causes the spaces between the liquids?
S: ...I mean the air causes the bubbles.
I: How do you think the bubbles were formed?
S: Well there's some spaces between the liquids and this air fills between that...the spaces.
I: If I was to say to you...ask you what is meant by boiling what would you say?
S: ...By boiling? All the spaces are filled...all the air fills the spaces.
I: And what would you say this was coming out of the spout?
S: Those are the extra...
I: You know when a kettles boils something comes out of the spout, what do you call that?
S: What's comes out?
I: Yeah
S: Vapour?
I: Where does that vapour come from?
S: The water.
I: Could you say anything more about how the bubbles are formed?
S: I don't think so.

Card 5

I: Here we have some sugar in warm water, if you stir the sugar up...
K: The sugar will melt
I: The sugar will melt you think?
S: Yes.
I: Where do you think has gone?
S: They have turned to liquid.
I: It's turned to liquid.
S: Yeah, the sugar particles have turned to liquid
I: The sugar particles have turned to liquid?
S: Yes.
I: You see at the bottom a few crystals that haven't gone away even though you've stirred and stirred?
S: Yes
I: Do you know why that happens?
S: No (laughs) but I've experienced that.
I: Do you think you could get the sugar back again, say you put in two spoons and stirred and most of it seems to have gone, could you get the sugar back out of the water again?
S: I don't think so.
I: You think it's a permanent change?
S: Yes it's a permanent change.

Appendix H

The Categorised Qualitative Alternative Justifications Presented by Students in the Science Concept Survey.

Item 1 - Indian (*the number in brackets denotes the number of responses in any category)
Energy is released whenever there is a change in the state of matter **(9)***
Because the particles come apart **(4)**
Heat energy is released when bonds are broken (hydrogen and covalent) **(2)**
Because this process involves condensation **(2)**
When the particles are heated they releases energy **(2)**
They releases cold energy **(1) (**indicates correct T/F choice)
Fijian
Energy is released whenever there is a change in the state of matter **(9)**
Because the particles come apart **(4)**
Heat energy is released when bonds are broken (hydrogen and covalent) **(1)**
Because this process involves condensation **(2)**
There is energy within the particles of ice before it melts **(3)**
They releases cold energy(1)**
Because the particles move closer to each other **(1)**
Because it has gone back to its normal state **(1)**
Because the glass becomes warmer during the process **(2)**
Because they turn into a solution form **(1)**
Because when something is heated it releases heat **(1)**
Item 2 - Indian
Particles in solid are held together tightly with no space to vibrate **(22)**
There is no heat and particles only vibrate when heat is applied **(3)**
Because the vibration cannot be seen nor felt **(1)**
If the particles moved the ice would form circles instead of cubes **(1)**
Fijian
Particles in solid are held together tightly with no space to vibrate **(8)**
There is no heat and particles only vibrate when heat is applied **(3)**
Because ice is liquid **(2)**
Item 3 - Indian
It comes from the ice cubes (or water) inside the glass **(4)**
The heat energy that is released forms into water droplets **(1)**
Fijian
It comes from the ice cubes (or water) inside the glass **(15)**
The heat energy that is released forms into water droplets **(2)**
It is from the water vapour released during heating **(1)**
It comes from the glass itself **(1)**
Item 4 - Indians
The humidity provides the heat energy for melting to occur **(24)**
The humidity affects the pressure which produces melting **(2)**
High humidity means less water particles in air so ice would melt faster **(1)**
Humidity makes the ice particles move apart **(1)**
High humidity causes water to evaporate **(1)**

Fijian

The humidity provides the heat energy for melting to occur **(17)**
The humidity affects the pressure which produces melting **(1)**
Humidity causes the ice particles to move closer **(1)**
It is the environment that causes the ice cubes to melt **(1)**

<u>Item 5</u> - Indians

Because the sun's heat absorbs water in the process of evaporation **(37)**
The sun's rays heat the water particles which expand and so turn into gas **(1)**
The water in the puddles has vibrated **(1)**

Fijian

Because the sun's heat absorbs water in the process of evaporation **(29)**
The sun's rays heat up the puddles and changed it into air **(2)**
The water is heated up and changed into clouds **(2)**

<u>Item 6</u> - Indian

Because when light is present heat is also present **(5)**
Where there is light energy it changes into heat energy **(4)**
Because both release heat **(2)**
Heat and light energy travel together, they have the same wavelength of rays **(1)**
The heat is needed for absorbing and light for slowing the pace of the liquid **(1)**
Because both use energy **(1)**
Because air is also needed **(1)

Fijian

Because when light is present heat is also present **(6)**
Because heat comes from light **(3)**
Because they are both elements of the sun **(1)**
Because they both contain energy **(1)**
Because both release heat **(1)**

<u>Item 7</u> - Indian

Water has gaps filled up with air spaces which are released upon heating **(15)**
When water is heated it turns into air **(8)**
Water particles move apart and so air moves in to fill the spaces causing bubbles **(7)**
Because you can see the air spaces (bubbles) inside **(2)**
When water is heated it gives off oxygen or hydrogen which are components of air **(2)**

Fijian

Water has gaps filled up with air spaces which are released upon heating **(10)**
Water particles move apart and so air moves in to fill the spaces causing bubbles **(4)**
When water is heated it turns into air **(3)**
Any bubbles must have air inside **(2)**
When water is heated it gives off oxygen or hydrogen which are components of air **(1)**
Because condensation is taking place **(1)**
The bubbles are made of heat energy **(1)**

<u>Item 8</u> - Indian

Because when water evaporates it changes into air **(21)**
The water particles gain energy and so change into air **(4)**
The chemical bonds between the water particles break and it forms air **(1)**
It will change into very fine particles and escape into the atmosphere **(1)**

Fijian

Because when water evaporates it changes into air **(17)**

The water particles gain energy and so change into air **(4)**
Because if you keep on heating there will be no more water left inside **(3)**
Because water has a boiling point of 100C **(2)**
Because heat makes the water particles light **(1)**
It will change into cold air **(1)**
The water will condense to air **(1)**

<u>Item 9</u> - Indian

Because it will get mixed with air **(1)**
It will evaporate **(1)**
Because it has already changed from water to vapour **(1)**

Fijian

The kettle once it cools can't produce water again **(1)**
The gas coming out of the spout will turn into air and disappear **(1)**
It is absorbed into the atmosphere **(1)**

<u>Item 10</u> - Indian

As the water vapour escapes it leaves a vacuum behind **(14)**
Because all of the air gets removed from the boiling water **(6)**
The movement of the water particles produces a vacuum **(1)**
We can see bubbles when water is heated **(1)**

Fijian

As the water vapour escapes it leaves a vacuum behind **(6)**
The movement of the water particles produces a vacuum **(5)**
We can see bubbles when water is heated **(4)**
Because all of the air gets removed from the boiling water **(2)**
Water changes to air so there is more pressure in the liquid since the air is hot **(1)**

<u>Item 11</u> - Indian

Because it needs to be changed into water again **(11)**
Because hot and cold things attract each other **(8)**
Because you can see water droplets on the window pane after some time **(2)**
It is moving from low to high pressure **(1)**

Fijian

Because hot and cold things attract each other **(8)**
Because hot steam will want to find a place to rest **(3)**
Because it needs to be changed into water again **(1)**
The vapour particles are moving rapidly and want to stabilise themselves **(1)**
The cold surface needs heat in order to break the bonds between particles **(1)**
Because the window pane is cold and contains water or moisture **(1)**

<u>Item 12</u> - Indian

They are attracted and so move faster **(5)**
The particles become heavier **(1)**
They will change to gas **(1)**
It depends on the wind direction **(1)**

Fijian

They are attracted and so move faster **(2)**
The particles become heavier **(2)**
Because there is a lot of space **(1)**

<u>Item 13</u> - Indian

Because the water has still got enough heat to cause this to happen **(1)**

Fijian
Heat from the kettle had been absorbed by the glass causing it to sweat **(4)**
Because air is changed into liquid producing sweat **(2)**
The glass is heated up causing it to vibrate and sweat **(1)**
It is just like when our body gets heated **(1)**
The difference in temperature causes sweating **(1)**
<u>Item 14</u> - Indian
The weight does not change because the wax has melted and solidified again **(19)**
The only thing which changes is the shape of the wax **(8)**
There is no chemical change only a physical change, so there is no change in mass **(5)**
It will gain weight **(1)**
Fijian
The weight does not change because the wax has melted and solidified again **(11)**
The only thing which changes is the shape of the wax **(3)**
It will gain weight (because energy has been added) **(3)**
No particles will have been lost **(2)**
Some of its weight has been converted to heat and light energy **(1)
<u>Item 15</u> - Indian
Any solid when heated changes to liquid and then a gas **(4)**
When wax melts it changes to water **(2)**
Fijian
When wax melts it changes to water **(3)**
Wax melts to water and after more heating it changes to air **(2)**
Because we can see the gas coming out from the candle as it burns **(1)**
<u>Item 16</u> - Indian
**Energy is also produced (7)
Sound energy is also given out **(2)
Burning uses oxygen to produce heat and light **(1)**
Fijian
Energy is also produced **(4)
It also produces air **(3)
Because heat and light contain energy **(2)**
Sound energy is also given out **(1)
Only heat is produced **(1)
Because we can see the light and feel the heat **(1)**
Because oxygen is involved **(1)**
<u>Item 17</u> - Indian
Because both burning and melting require heat **(1)**
Because melting takes place when you burn something **(1)**
Fijian
Because both burning and melting require heat **(5)**
Because melting takes place when you burn something **(3)**
Melting and burning both use oxygen therefore they are the same **(1)**
They are the same because they both produce energy as an output **(1)**
Both these processes need carbon dioxide **(1)
<u>Item 18</u> - Indian
Because some has been changed into heat and energy **(1)**
The particles are not as close after the wax re-solidifies **(1)**

Fijian
Because some of wax has been lost during the melting process **(9)**
The structure of the wax will have changed **(5)**
The wax which has melted and re-solidified has lost energy **(1)**
The wax which has melted and re-solidified has gained energy **(1)**
<u>Item 19</u> - Indian
Because energy is released (by particle breakdown) during the burning process **(16)**
Energy is needed in the burning process **(4)**
Because there is less substance after burning **(3)**
Because carbon is changed to energy during burning **(3)**
Because we can see smoke coming from the candle as it burns **(1)**
Fijian
Because energy is released during the burning process **(14)**
Energy is needed in the burning process **(3)**
All of the candle's matter is changed into energy **(3)
When something is burned part of its matter is changed into air **(2)**
Because particles are lost as energy **(1)**
<u>Item 20</u> - Indian
The sugar melts after it has been mixed with the water **(16)
Heat provides the energy to melt the sugar crystals **(7)**
The solid sugar crystals have to melt in order to mix with the water **(6)**
Fijian
The sugar melts after it has been mixed with the water **(22)
Heat provides the energy to melt the sugar crystals **(5)**
The sugar crystals absorb water particles **(2)**
The sugar melts due to the stirring **(1)**
Sugar is not soluble in water **(1)
<u>Item 21</u> - Indian
Because sugar must change into water if it is to dissolve **(13)**
The sugar melts so it changes into water **(6)**
When the sugar is stirred it changes into water **(2)**
Fijian
Because sugar must change into water if it is to dissolve **(15)**
The sugar melts so it changes into water **(6)**
Sugar can only change to water if the crystals are very small **(3)**
Because we see there is no sugar left **(2)**
Since sugar came from a liquid it will go back to a liquid **(2)**
When the sugar is stirred it changes into water **(1)**
Because water has broken the chemical bonds in the sugar **(1)**
<u>Item 22</u> - Indian
The friction causes the crystals to lose particles and become smaller **(10)**
Because as they are stirred the crystals gain energy and thus change size **(2)**
Because you can see a lot of collisions taking place as the crystals are stirred **(1)**
Rubbing weakens the intermolecular forces holding the sugar molecules together **(1)**
Fijian
The friction causes the crystals to lose particles and become smaller **(9)**
The sugar gets smaller partly by the rubbing and partly due to dissolving **(7)**
After stirring we can see that the sugar crystals get smaller **(3)**

The rubbing helps to heat up the sugar particles and loosen them **(2)**
Rubbing causes the sugar particles to melt with the help of the water **(1)**
<u>Item 23</u> - Indian
The sugar does not go between the water particles, it dissolves **(5)**
The sugar particles have changed into water **(2)**
The water causes the sugar particles to melt **(1)**
Fijian
The sugar does not go between the water particles, it dissolves **(4)**
The sugar particles have changed into water because of stirring **(2)**
After stirring none of the sugar particles can be seen **(1)**
<u>Item 24</u> - Indian
The bonding between the particles is too strong **(4)**
Because these crystals are insoluble **(1)**
Fijian
Because these crystals are insoluble **(5)**
The bonding between the particles is too strong **(3)**
They must be like sand particles and therefore insoluble.
These crystals must be made of a different chemical **(1)**
These crystals are too big for the spoon to dissolve **(1)**
<u>Item 25</u> - Indian
Because dissolving is not a reversible process **(2)**
You will get burnt sugar not the crystals **(2)**
If you heat the solution the sugar will evaporate with the water **(1)**
The particles of sugar have split and it is hard to get them back together again **(1)**
To get the sugar crystals back requires too much heat **(1)**
Fijian
Because dissolving is not a reversible process **(3)**
The sugar has changed to water and cannot be turned back into sugar again **(3)**
The sugar particles have been too thoroughly mixed with the water particles **(3)**
The particles of sugar have split and it is hard to get them back together again **(1)**
<u>Item 26</u> - Indian
Air particles expand when heated **(9)**
When particles gain energy they become lighter **(3)**
Heat breaks the link between the air particles and they can move about freely **(2)**
Warm air rises **(1)**
Fijian
Air particles expand when heated **(8)**
The water evaporates and changes into air which rises expanding the balloon **(5)**
The heat takes up a lot of space **(2)**
The air particles want to get away from each other **(1)**
Heat makes things lighter **(1)**
Warm air rises **(1)**
<u>Item 27</u> - Indian
The air particles will try to move out (or rise) so there will be more in the balloon **(17)**
There will be more particles in the balloon as we see the balloon get bigger **(1)**
Some of the particles might have escaped **(1)**
Because the air pressure in the two differs **(1)**
The size of the balloon and the bottle are not the same **(1)**

Fijian
The air particles will try to move out (or rise) so there will be more in the balloon **(14)**
The air particles expand when heated **(6)**
When air enters the balloon it turns into water vapour **(3)**
More air particles will be created after heating **(3)**
The size of the balloon and the bottle are not the same **(3)**
There will be more particles in the balloon as we see the balloon get bigger **(1)**
Because there are already some air particles in the balloon **(1)**
The amount of energy in the hot water will decrease **(1)**

Item 28 - Indian

Fijian
The air particles will be too close to each other to allow them to move about **(1)**

Item 29 - Indian
The acetone in the liquid form is heavier than in the acetone in gas form **(12)**
Because acetone has changed to air which is lighter than liquid **(3)**
After heating the acetone would have burnt or disappeared making it lighter **(2)**
After heating the acetone particles expand and therefore weigh more **(1)**
Because the acetone has combined with oxygen **(1)**
Because some energy will have been lost **(1)**

Fijian
The acetone in the liquid form is heavier than in the acetone in gas form **(19)**
After heating the acetone disappears **(4)**
Because acetone has changed to air which is lighter than liquid **(3)**
Because some energy will have been lost **(3)**
Because air pressure has increased after heating so it has increased weight **(1)**

Item 30 - Indian
The acetone particles will evaporate and form into air **(8)**
The particles will collide together and combine **(5)**
The acetone must have combined with air as it is not seen **(3)**

Fijian
The acetone particles will evaporate and form into air **(6)**
Because they are in the same state now **(4)**
Because heat will make the particles move faster **(3)**
Acetone particles will be absorbed into the air particles **(1)**
There is no space for the acetone particles to move so they combine with the air particles **(1)**

Item 31 - Indian
Because it has changed into the air and can't change back **(2)**
A chemical change has taken place which cannot be reversed **(1)**
Once absorbed by the air the acetone will disappear **(1)**

Fijian
Because it has changed into the air and can't change back **(2)**
It will only be possible to get liquid water back **(2)**

Item 32 - Indian
The acetone will change into bubbles and will stick to the sides of the tube **(1)**

Fijian
Because acetone is a volatile liquid **(1)**

Item 33 - Indian
Space is created in the bottle therefore air is sucked in **(19)**
Air has been lost from the bottle allowing the balloon to get bigger **(4)**
The plastic sheet pulls the air inside **(3)**
The pressure outside the bottle causes the air to be pulled in **(1)**
Air is sucked in by gravity **(1)**
The movement of air has nothing to do with the plastic sheet **(1)
Fijian
Space is created in the bottle therefore air is sucked in **(5)**
It is a result of air pressure increasing inside the balloon **(3)**
Air is sucked in by gravity **(2)**
The plastic sheet pulls the air inside **(1)**
It is due to compressing of air **(1)**
Item 34 - Indian
Gravity pulls the air inside **(3)**
Gravity is the downward pull of the earth and works everywhere **(3)**
Gravity works together with the pressure **(1)**
Gravity pulls the balloon down **(1)**
The plastic sheet is pulled towards the gravity **(1)**
Gravity provides the energy to pull the air into the bottle **(1)**
Fijian
Gravity pulls the air inside **(5)**
Gravity is creating the pressure which causes the air to move **(4)**
When something moves down, gravity must be involved **(2)**
Because air is too light to move by itself **(1)**
The plastic sheet causes the force of gravity **(1)**
Item 35 - Indian
The pressure inside the bottle has increased **(8)**
The pressure inside the bottle remains the same **(4)**
The pressure increases because there are less particles and more gaps to fill.
The pressure has increased because the plastic has been forced down **(2)**
Fijian
The pressure inside the bottle has increased.(causing the balloon to expand) **(7)**
The pressure inside the bottle remains the same **(2)**
Extra energy has been applied to the air so the pressure increases **(1)**
Item 36
No expanded alternative conceptions.
Item 37 - Indian
There is hardly any space for the particles to move **(7)**
Because both syringes are sealed and nothing can escape **(6)**
There is too much pressure inside each **(2)**
Because the energy inside is equal to the energy outside **(1)**
Fijian
There is hardly any space for the particles to move **(11)**
Because both syringes are sealed and nothing can escape **(10)**
Because both air and water have got weight **(1)**
Because the force of gravity will be high **(1)**
The one filled with water can be compress, but not the air one **(1)

Item 38 - Indian
The water will enter the glass and the paper will get wet **(4)
The water moves apart as the glass is pushed down **(3)**
The force makes it difficult for the water to fill up the glass and give out bubbles **(3)**
Because the heat from the students hand will keep the water away **(1)**
Because a vacuum is created inside **(1)**
Fijian
The water will enter the glass and the paper will get wet **(7)
The water moves apart as the glass is pushed down **(1)**
Since their is no air space, water cannot enter the glass **(1)**
It depends on far the glass is immersed **(1)**
Item 39 - Indian
Heat causes metal to expand **(12)**
Because metal is a good conductor **(1)**
The metal ball remains the same size although its particles get bigger **(1)**
Because the particles gets softer **(1)**
They get mixed with air so become bigger **(1)**
Fijian
Heat causes metal to expand **(9)**
Heat tends to increase the amount of a substance **(1)**
This is the only way the particles can escape, by becoming bigger **(1)**
The heated particles start to hit one another causing them to get bigger **(1)**
When metals are heated they become smaller in size **(1)
Item 40 - Indian
When the particles cannot hold any more energy they will burst **(6)**
When the particles try to move and there is no space might burst **(5)**
This is what happens when we see cracks in the metal ball **(2)**
The particles will melt and thus disintegrate **(1)**
Fijian
When the particles cannot hold any more energy they will burst **(8)**
When the particles try to move and there is no space might burst **(1)**
This is what happens when we see cracks in the metal ball **(1)**
This is the concept of nuclear energy **(1)**
If its boiling point is exceeded the Van der Vaals forces break **(1)**
Item 41 - Indian
It is only the air particles (within the ball) which will come closer **(1)**
They won't lose energy **(1)**
Fijian
They will remain in the same position after heating **(2)**
Item 42 - Indian
It depends on the type of solid **(1)**
Fijian
There is more space between the particles of a solid than a liquid **(3)**
The particles of a liquid are tightly packed together **(1)**
Item 43 - Indian
Because only gas particles move freely not liquid particles **(5)**
The particles of a liquid are too tightly packed to move around (vibrate only) **(4)**

Fijian
Because only gas particles move freely not liquid particles **(4)**
The particles of a liquid are too tightly packed to move around **(3)**
Liquid particles take up the shape of a container so they are not free to move around **(1)**

<u>Item 44</u> - Indian
Air is present everywhere **(6)**
The air spaces between the particles allows the metal to expand when heated **(4)**
There is enough space between the particles to allow air to fit in **(3)**
There are air particles but fixed at one place **(1)**
When the ball forms some air is trapped between the metal particles **(1)**

Fijian
Air is present everywhere **(10)**
The air spaces between the particles allows the metal to expand when heated **(8)**

<u>Item 45</u> - Indian
Air is weightless **(2)**
Air cannot be weighed because it is too mobile **(1)**
The air particles are far apart and so has no volume **(1)**
Air is near to a vacuum and a vacuum has no weight **(1)**
If air had weight it would be impossible to fly **(1)**

Fijian
The air particles are far apart and have no weight **(2)**
Air cannot be weighed **(2)**
Air is weightless **(1)**
Air has no density **(1)**
Only compressed air has weight **(1)**

<u>Item 46</u> - Indian
Only if the air is compressed and under pressure **(2)**
Air does not have any particles **(1)**
This will only happen if the gas is heated **(1)**

Fijian
This will only happen if the gas is heated **(2)**
This will only happen if the gas is heated **(1)**

<u>Item 47</u> - Indian
Humidity gives energy to particles (due to more heat) and they move faster **(7)**
Pressure is directly proportional to humidity **(3)**
High humidity means more particles therefore more pressure **(3)**

Fijian
Humidity gives energy to particles (due to more heat) and they move faster **(7)**
Pressure is directly proportional to humidity **(3)**
Humidity gets lower as air pressure gets higher **(2)
High humidity causes less gravitational force **(1)**

<u>Item 48</u> - Indian
Matter gets heavier when it loses energy because the particles move closer **(4)
Loss of energy causes a change of state and thus a loss of weight **(3)**
Energy has some weight **(2)**
Because the particles move away from each other **(1)**
When matter losses energy it loses some of its force **(1)**

Fijian

Matter gets heavier when it loses energy because the particles move closer **(7)

A substance losses some particles when it loses energy **(6)**

It is the energy which gives a substance weight **(4)**

Loss of energy causes decay **(1)**

Energy can evaporate **(1)**

<u>Item 49</u> - Indian

Particles can be living or non-living depending on the type of matter **(22)

That is why they move around **(1)**

The states of matter are living **(1)**

Particles are living because they have weight **(1)**

Fijian

Particles can be living or non-living depending on the type of matter **(11)

That is why they move around **(1)**

<u>Item 50</u> - Indian

Because the particles move away from each other when heated **(10)**

Because more collisions occur between particles **(2)**

Matter expands when it is heated **(1)**

The electrons are disrupted **(1)**

Fijian

Matter expands when it is heated **(7)**

Because the particles move away from each other when heated **(6)**

Because more collisions occur between particles **(1)**

The water breaks up into H+ and O- which repel **(1)**

That is why pressure increases when a gas is heated **(1)**

Particles attract each other when heated **(1)